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CONTENTS

Vol. XI, Part III

(June 1941)

The Editorial Committee of the Imperial Council of Agricultural Research, India, takes no responsibility for the opinions expressed in this Journal.

PAGE

ORIGINAL ARTICLES

ECONOMICS OF MANURING

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(Received for publication on 3 March 1941)

(With four text-figures)

AN all-important question regarding manuring is, 'Does it pay ?' This means, of course, 'Does the money value of the additional crop obtained exceed the price paid for the manure applied ?' A subsidiary but also important question is, 'At what point in the price paid for the manure applied does it cease to pay ?' Owing to the high prices of artificial manures during war time the economics of manuring has received a good deal of attention in a few places in India, but as Burns [1940] has recently pointed out, 'a great deal remains to be done in getting the economics of manuring down to a precision that can be expressed in a table or graph '.

The word ' precision ' in the above quotation is exceedingly important. The fact that the value of the extra crop raised as a result of manuring is more than the price of the manure applied, including the incidental charges of application, cannot by itself, without consideration of the experimental errors to which the excess (or profit) is subject, establish the generalization that it pays to manure. The appropriate factor to consider would appear to be the index of probability that a profit as large as or larger than the one observed in the experiment conducted would occur in future. Only when this probability is found to be sufficiently large should we be justified in pronouncing a verdict that it would pay to manure a crop.

In a note published in *Current Science*, the author [Sukhatme, 1941] has briefly outlined the approach to the study of manurial trials from the economic aspect explained above. The main object of this paper is to present the test of significance for profit in its application to some actual data. The subsidiary objects are to determine the relationship between the value of the extra produce and the dose of manure, and to estimate the optimum dose of manuring with its standard error. The economic aspect of manuring paddy with groundnut-cake has of late been receiving special attention in India. It is proposed to use the data on this subject for illustrating the method. It is, however, necessary to emphasize that there have been very few manurial trials on paddy carried out in the past. The data have been chiefly used for illustration and the conclusions reached in regard to manuring paddy with oil-cake have to be considered to provide indications as such.

The data have been taken from the publications of the Imperial Council of Agricultural Research on manurial experiments on rice conducted in the provinces and states of India during 1932-38 [Vaidyanathan, 1938]. It is possible that there might be some experiments relating to the manuring of paddy with groundnut-cake conducted in the past which have not found a

place in the two Imperial Council of Agricultural Research publications. The author would be grateful if details of any such experiments were communicated to him as their consideration, when possible, would doubtless serve to enhance the utility and generality of the conclusions reached in this paper.

Looking through the two volumes on manurial experiments on rice referred to above one is struck by the paucity of the published information relating to replicated field trials on manuring paddy with groundnut-cake. There are to be found just three experiments, one at Maruteru and two at Pattambi in the Madras province which are replicated and which supply valid estimates of error. At Maruteru in the West Godavari District, the experiment was conducted with a departmental variety for three successive years on black deltaic soil. At Pattambi on the west coast the soil was shallow laterite in the two sites on which the experiments were conducted. In one site two crops were raised in each of the two years of the experiment and in the other one crop was raised in a single year. None of the experiments was conducted solely for the purpose of testing the effect of the groundnut-cake in various doses on paddy, but each of them involved the application of other manures as well. Relevant details of these experiments taken from the two volumes are shown in Table I.

A glance at the table shows that with the exception of one trial at Pattambi (crop 1, 1936-37) the mean yields obtained in other trials are of the order of 2,000 lb. per acre. The low mean yield at Pattambi (crop 1, 1936-37) was due to the attack of insect pests in the early stages of the crop and of birds in the later stages. Statistically it appears to fall outside the range to be expected from the remaining group of trials and consequently in a combined review which is attempted here it has been thought advisable to exclude the results of this trial.

Table II shows the absolute and the percentage increases in yields of plots manured with groundnut-cake over plots which did not receive groundnut-cake and the results of the application of the t-test of significance at the 5 per cent level. It will be seen from Table II that there is a very good response to the application of groundnut-cake to paddy, the response generally increasing with the increasing dose of manure. The mean percentage response at the dose of 15-16 lb. of N per acre, applied singly or in combination with some other organic manure, works out to be 16. The mean percentage increase is seen to be 31 at the dose from 30 to 32 lb. of N applied singly or in combination and is about 50 when the dose is 48 lb. N per acre. The last but one column shows the significance or otherwise of the increased yields as judged by the t-test. At the dose of 15 lb. N per acre the increase in yield secured is not always significant, showing that the dose is slightly inadequate. It is apparent, however, that when the groundnut-cake is applied in quantities to supply a dose of 30-32 lb. N per acre or above, it gives a significantly higher yield than if no groundnut-cake manure was applied.

A significant increase in yield may or may not be accompanied by a significant profit, or, in other words, the value secured for extra crop may or may not significantly exceed the price of manure applied. The significance of profit will depend on the magnitude of the profit secured in relation to its error which in its turn will be determined by the prices obtaining for paddy and manure.

TABLE I

Relevant details of the manurial experiments

No.	Year	Index	Variety	Soil	Details of treatments	Layout	Mean yields of treatments in pounds per acre								Standard error of treatment mean	Standard error percentage
					Pattambi—Madras		Treatments									
I	1936-37	A-I Crop	Ptb-5	Sandy loam	1. Groundnut-cake to supply 30 lb. N	9 × 6 randomized block		1	2	3	4	5	6	7		
	1936-37	B-II „	Ptb-3		2. Green leaf 15 lb. N + Groundnut-cake 15 lb. N		A	965	745	841	692	678	973	690	82·09	10·95
					3. Cattle manure 15 lb. N + Groundnut-cake 15 lb. N		B	2159	2005	2051	1706	1660	1937	1690	45·88	2·44
	1937-38	C-I „	Ptb-5		4. Green leaf alone to supply 15 lb. N		C	3133	2996	2644	2767	2657	2825	2580	84·94	3·04
		D-II „	Ptb-3		5. Cattle manure to supply 15 lb. N		D	1741	1634	1707	1431	1066	1441	1401	92·20	6·22
					6. Groundnut-cake to supply 15 lb. N											
					7. No manure											
II	1937-38	II Crop .	Ptb-3	„	1. Groundnut-cake to supply 30 lb. N	10 × 6 R. block		1	2							
					2. No manure			2256	1744						34·85	1·47
					Maruteru—Madras											
III	1934-35	A-II Crop	Mth-9	Black cotton soil, Godavari Delta	1. Groundnut-cake to supply 16 lb. N	24 × 7 randomized block		1	2	3	4					
	1935-36	B „	Mth-9		2. Groundnut-cake to supply 32 lb. N		A	1895	2061	2372	1478				94·12	3·79
	1936-37	C „	Mth-9		3. Groundnut-cake to supply 48 lb. N		B	1774	2004	2059	1462				66·82	3·50
					4. No manure		C	2025	2303	2549	1693				56·28	2·34

TABLE II

Showing significance or otherwise of the extra yield obtained from manuring with groundnut-cake

No.	Cake to supply	Index	Yield in pounds per acre: Cake treatment	Yield in pounds per acre: Non-cake treatment	Yield in pounds per acre: Increase	Yield in pounds per acre: Percentage increase	Critical difference at 5 per cent level of 't'	Sig. or not	Remarks
					Pattambi—Madras				
I(*a*)	15 lb. N	A	973	690	283	41·0	234·6	Yes	15 lb. N as ground nut-cake (G. C.) over no-manure
		B	1937	1690	247	14·6	131·1	,,	
		C	2825	2580	245	9·5	242·7	,,	
		D	1441	1401	40	2·9	263·5	No	
(*b*)	15 lb. N	A	745	692	53	7·7	As above	No	15 lb. N as green leaf + 15 lb. N as G. C. over 15 lb. N as green leaf
		B	2005	1706	299	17·5		Yes	
		C	2996	2767	229	8·3		No	
		D	1634	1431	203	14·2		,,	
(*c*)	15 lb. N	A	841	678	163	24·0	As above	,,	15 lb. N as cattle manure + 15 lb. N as G. C. over 15 lb. N as cattle manure
		B	2051	1660	391	23·6		Yes	
		C	2644	2657	...	...		No	
		D	1707	1066	641	60·1		Yes	
(*d*)	30 lb. N	A	965	690	275	39·9	As above	,,	30 lb. N as G. C. over no-manure.
		B	2159	1690	469	27·8		,,	
		C	3133	2580	553	21·4		,,	
		D	1741	1401	340	24·3		,,	
II	30 lb. N	...	2256	1744	512	29·4	99·2	,,	30 lb. N as G. C. over no-manure
					Maruteru—Madras				
III(*a*)	16 lb. N	A	1895	1478	417	28·2	262·9	,,	16 lb. N as G. C. over no-manure
		B	1774	1462	312	21·4	186·6	,,	
		C	2025	1693	332	19·6	157·2	,,	
(*b*)	32 lb. N	A	2061	1478	583	39·4	As above	,,	32 lb. N as G. C. over no-manure
		B	2004	1462	542	37·0		,,	
		C	2303	1693	610	36·0		,,	
(*c*)	48 lb. N	A	2372	1478	894	60·5	As above	,,	48 lb. N as G. C. over no-manure
		B	2059	1462	597	40·8		,,	
		C	2549	1693	856	50·6		,,	

For a given price of paddy, the value of yield per plot will be subject to the same experimental errors as the quantity of yield itself, so that if p is the price of paddy per unit weight and u the error variance of yield per plot, the error variance of value per plot will be merely p^2u. The error variance of a treatment mean value will be p^2u/r (r being the number of replications) and that of the difference in mean values of manured plots over non-manured

plots and hence that of the profit itself for a fixed price of manure will be $2p^2u/r$. The value of 't' will be simply given by the quotient of the profit by its standard error. When t will exceed the corresponding 5 per cent value, there would be ground for belief, with the risk of going wrong once in 20, that manuring would more than pay for its cost. The whole validity of the application of the t-test follows in fact by regarding the money value of yield rather than quantity as the measurable produce for manuring experiments.

It would be confusing if profit and its errors were to be worked out for each of the several comparisons set out in Table II at each of the different combinations of prices of paddy and of manure likely to prevail. It is in fact unnecessary to do so. Where trials have been repeated over a series of seasons as at Maruteru, it adds to the clarity and precision of the conclusions reached if the results of all the years are combined into a single test of significance. For the three trials at Maruteru this has been done in Table III. The figures in the body of the table represent the average profit in Rs. per acre obtained over the three years from each of the several doses of manure applied and for a variety of prices for paddy and manure shown in the first column and top row of the table. The last column gives the values of the critical difference, being the products of the standard errors of average profits with the 5 per-cent values of t. It will be clear that when a profit exceeds its corresponding critical difference, it may be considered statistically significant. Significant profits have been all put in italics in the table.

It will be seen that there is as it were a line running across the table dividing it into two portions, one where it pays to manure, the other where it does not. This is only to be expected; for if the price of manure is high, the price of paddy has to be proportionately higher if manuring is to pay. It will be seen that when the price per lb. of nitrogen in the cake is four annas (which at 7½ per cent recovery corresponds roughly to the price of Rs. 1-8 per maund of cake) manuring may be expected to pay even at the price of Rs. 2 per maund of paddy. For a price of six annas per lb. of N in the cake (which roughly corresponds to Rs. 2-4 a maund of cake) manuring is unlikely to pay at Rs. 2 a maund for paddy but can be expected to pay at prices slightly higher than Rs. 2. For higher prices of manures the price of paddy will be seen to be proportionately higher if manuring is to pay. At ten annas per pound of N in the cake manuring is unlikely to pay even at as high a price as Rs. 3-8 a maund of paddy. At the prices now prevailing namely about Rs. 3 a maund for paddy and Rs. 2 to Rs. 2/8 a maund for groundnut-cake, it appears that manuring with cake may almost certainly be expected to give a profit to the cultivator provided that the conditions obtaining in his farm in regard to soil and cultivation are not very different from those at Maruteru.

The results of the two experiments conducted at Pattambi are summarized in Table IV. The table is divided into three sub-tables. In the first the results of the application of groundnut-cake applied singly are presented. It will be seen that the dose of 15 lb. N is inadequate to give a significant profit even at the price of Rs. 3-8 a maund of paddy and the price of four annas per lb. N in the cake. It appears that paddy requires more of nitrogen in the black deltaic soils of Maruteru than in the laterite shallow soils to fetch a significant profit. The dose of 30 lb. N per acre would almost certainly give a significant profit at about the same prices of paddy and cake

TABLE III

Showing significance or otherwise, at various prices of paddy and manure, of extra yield obtained after deducting for the cost of manure applied

(Experiment conducted at Maruteru 1934-37)

Soil : black cotton

Manure / Price of paddy per maund	Price of groundnutcake to supply unit pound of nitrogen												Standard error of profit.	Critical difference
	At Rs. 0·625			At Rs. 0·500			As Rs. 0·375			At Rs. 0·250				
	Groundnut-cake supplying													
	16 lb.N	32 lb.N	48 lb.N	16 lb.N	32 lb.N	48 lb.N	16 lb.N	32 lb.N	48 lb.N	16 lb.N	32 lb.N	48 lb.N		
Rs. 3·5	5·06	4·63	3·30	*7·06*	*8·63*	*9·30*	*9·06*	*12·63*	*15·30*	*11·06*	*16·63*	*21·30*	2·57	5·15
Rs. 3·0	2·90	1·11	—1·45	*4·90*	*5·11*	*4·55*	*6·90*	*9·11*	*10·55*	*8·90*	*13·11*	*16·55*	2·21	4·41
Rs. 2·5	0·75	—2·41	—6·20	2·74	1·59	—0·20	*4·74*	*5·59*	*5·80*	*6·74*	*9·59*	*11·80*	1·84	3·68
Rs. 2·0	—1·40	—5·93	—10·95	0·58	—1·93	—4·95	2·58	2·07	1·05	*4·58*	*6·07*	*7·05*	1·47	2·94

Table IV

Showing significance or otherwise, at various prices of paddy and manure, of extra yield obtained after deducting for the cost of manure applied

(Experiment conducted at Pattambi 1936-38)

Soil : sandy loam

Price of paddy per maund	Manure	Price of groundnut-cake to supply unit pound of nitrogen								Standard error of profit	Critical difference
		At Rs. 0·625		At Rs. 0·500		At Rs. 0·375		At Rs. 0·250			
		Groundnut-cake supplying									
		15 lb. N	30 lb. N	15 lb. N	30 lb. N	15 lb. N	30 lb. N	15 lb. N	30 lb. N		
		(a) *For increase over no-manure*									
Rs. 3·5	I	—1·85	0·56	0·03	4·31	1·91	*8·06*	3·79	*11·81*	2·67	5·35
	II		3·03		*6·78*		*10·53*		*14·28*	2·09	4·21
Rs. 3·0	I	—2·93	—2·20	—1·05	1·55	0·83	*5·30*	2·71	*9·05*	2·29	4·59
	II		—0·08		*3·67*		*7·42*		*11·17*	1·80	3·62
Rs. 2·5	I	—4·01	—4·96	—2·13	—1·21	—0·25	2·54	1·63	*6·29*	1·91	3·82
	II		—3·19		0·56		*4·31*		*8·06*	1·50	3·01
Rs. 2·0	I	—5·09	—7·72	—3·21	—3·97	—1·33	—0·22	0·55	*3·53*	1·53	3·06
	II		—6·30		—2·55		1·20		*4·95*	1·20	2·41
		(b) *For increase over 15 lb. N as green leaf*									
Rs. 3·5		1·00	...	2·88	...	4·76	...	*6·64*	...	2·67	5·35
Rs. 3·0		—0·48	...	1·40	...	3·28	...	*5·16*	...	2·29	4·59
Rs. 2·5		—1·96	...	—0·08	...	1·80	...	3·68	...	1·91	3·82
Rs. 2·0		—3·44	...	—1·56	...	0·32	...	2·20	...	1·53	3·06
		(c) *For increase over 15 lb. N as cattle manure*									
Rs. 3·5		5·08	...	*6·96*	...	*8·84*	...	*10·72*	...	2·67	5·35
Rs. 3·0		3·02	...	*4·90*	...	*6·78*	...	*8·66*	...	2·29	4·59
Rs. 2·5		0·96	...	2·84	...	*4·72*	...	*6·60*	...	1·91	3·82
Rs. 2·0		—1·10	...	0·78	...	2·66	...	*4·54*	...	1·53	3·06

as found at Maruteru. Table IV (*b*) shows that groundnut-cake to supply 15 lb. N per acre is adequate to return a profit if applied in combination with cattle manure, in roughly the same range of prices as at Maruteru. It will thus be seen that while the effect of cattle manure is beneficial, that of green-leaf is not as seen from Table IV (*c*).

Figs. 1-4 represent the results summarized in Table III of the three years experiment at Maruteru. The four diagrams (Figs. 1-4) correspond to the four rates of paddy. The amount of nitrogen as groundnut-cake applied per acre is plotted along the horizontal axis, and the value of extra crop and of manure applied are plotted along the vertical axis. The continuous curve represents the average value of the extra crop raised against the dose of manure applied. The four straight lines give the cost of manure applied at the rates shown beside them. The dotted curve gives the values of extra produce minus the critical errors at the 5 per cent level of *t*. For convenience this curve may be called the lower fiducial curve of the values of extra produce at the 5 per cent level of *t*.

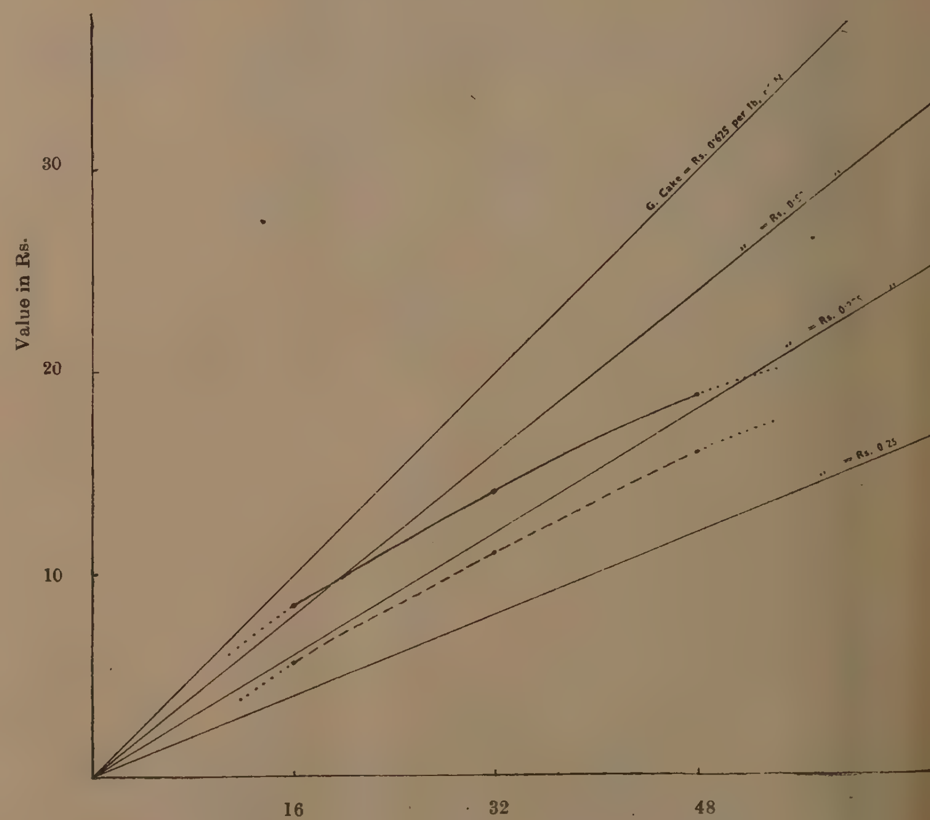
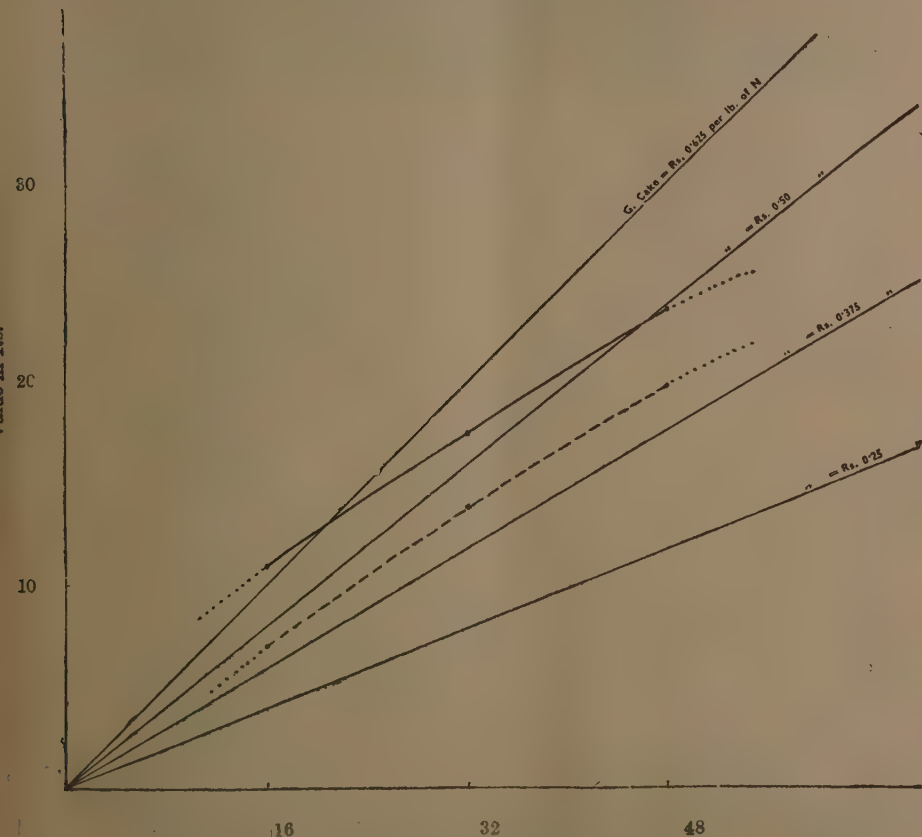


FIG. 1 Price of paddy Rs. 2 per maund

The diagrams are self-explanatory and can be read without any difficulty. It is obvious that if the value of the ordinate of the dotted curve is more than the value of the ordinate of the cost line for manure, manuring may be expected to pay for the dose applied, e.g. in Fig. 3 within the range of doses tried the dotted curve lies wholly above the cost line for manure corresponding to the rate of eight annas per lb. of N in the cake. This shows that at the price of Rs. 3 per maund of paddy manuring in the range from 16 lb. N to 48 lb. N per acre may be expected to pay up to the rate of eight annas per lb. of N in the cake.

The precise determination of the optimum dose of manuring implied in the subsidiary question regarding manuring presupposes a known form of relationship between the value of extra produce and the dose of manure applied. Field experiments rarely include more than three to four doses of manuring,



Pounds of nitrogen in the form of groundnut-cake

FIG. 2 Price of paddy Rs. 2-8 per maund

which are clearly too few to provide an adequate indication of this relationship. It would, however, appear reasonable to assume that a second degree parabola of the form $v = \alpha + \beta d + \gamma d^2$, where v denotes money value and d the dose of manure, would adequately represent the relation. Its shape would be as shown in the four diagrams with concavity facing the horizontal axis. It is a curve often used to represent the relation in question and is clearly the one that commonsense and facts support. Thus Andrews [1940] has recently used it in his paper on the elimination of differences in investment in the evaluation of the fertilizer analyses. The equation to the straight line giving the cost of manure is clearly $v = qd$, where q is the price per unit dose of manure. It will be readily seen that the optimum dose is given by the point where the tangent to the value curve is parallel to the cost line for manure. In the notation used above the optimum dose $\hat{d}$ is given by $\frac{q-\beta}{2\gamma}$.

In the experiment at Maruteru the manure was applied in only three doses, the corresponding average extra yields and values of produce being those shown on the next page:—

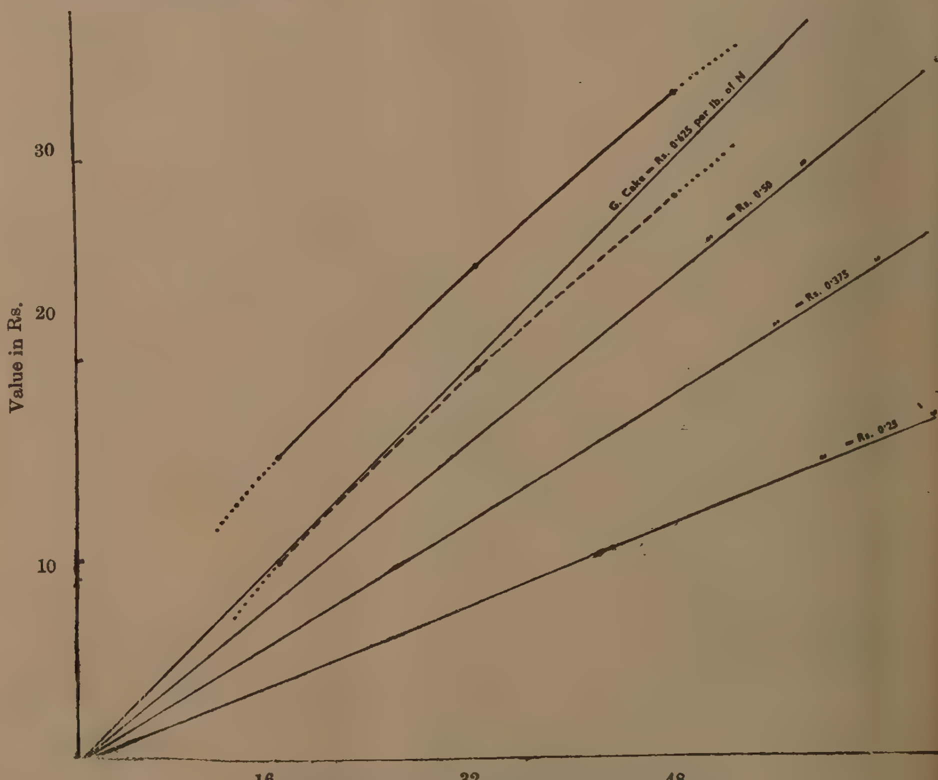


FIG. 3. Price of paddy Rs. 3 per maund

Dose of manure (in units of 16 lb. of N in the cake)	Average extra yields in lb.	Value in Rs. of extra produce at rates per maund			
		Rs. A. 3 8	Rs. A. 3 0	Rs. A. 2 8	Rs. A. 2 0
1	354	15·0565	12·9056	10·7546	8·6037
2	579	24·6263	21·1083	17·5902	14·0722
3	783	33·3030	28·5484	23·7878	19·0303

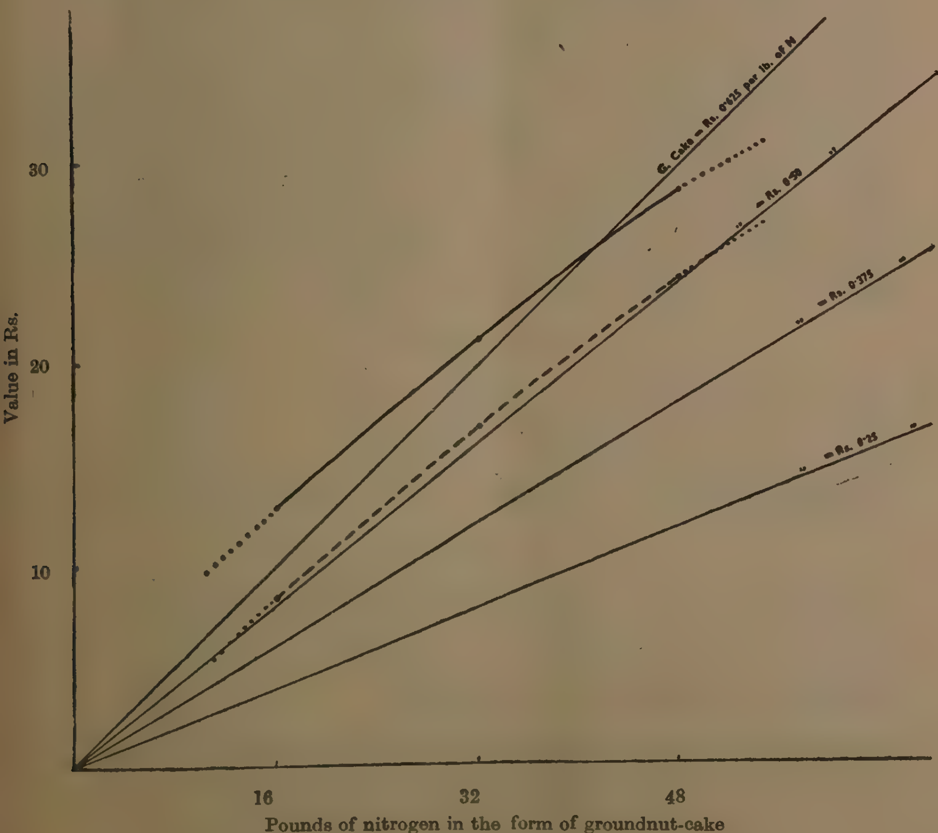


FIG. 4. Price of paddy Rs. 3-8 per maund

The four equations to the parabolas corresponding to the four rates of paddy representing the value in rupees of the average extra produce in terms of the dose of manure in lb. of N applied are readily found to be :—

Price of paddy per maund	
Rs. 3-8	$v = 4 \cdot 5935 + 10 \cdot 9088\, d - 2 \cdot 4465\, d^2$
Rs. 3	$v = 3 \cdot 9373 + 9 \cdot 3504\, d - 0 \cdot 3827\, d^2$
Rs. 2-8	$v = 3 \cdot 2811 + 7 \cdot 7920\, d - 0 \cdot 3190\, d^2$
Rs. 2	$v = 2 \cdot 6249 + 6 \cdot 2336\, d - 0 \cdot 2552\, d^2$

The values for the optimum dose of manure are obtained by substituting in the formula for $\hat{d}$ values for q, β and γ, e.g. at the prices of Rs. 3 per maund of paddy and Rs. 8 per 16 lb. of N in the cake, the optimum dose in units of 16 lb. of N will be $\frac{8-9 \cdot 3504}{-2 \times 0 \cdot 3827}$.

or $1 \cdot 764$ which is equivalent to the dose of $28 \cdot 2$ lb. of nitrogen in the cake. Values for the optimum dose corresponding to other combinations of prices of paddy and manure can be similarly obtained. These have not been, however, tabulated in the paper as they are mostly found to lie outside the range of doses included in the experiments. They serve to indicate the necessity for including higher doses in future trials, but beyond that not much value can be placed on them. They are moreover subject to very large sampling errors. The derivation of the formulæ for the standard error of the optimum dose and of the profit to be expected at any dose desired to be applied together with its standard error is briefly outlined in the Appendix.

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APPENDIX

The equation to the value curve can be alternatively put in the form

$$v = \bar{v} + b_1 \varepsilon_1 + b_2 \varepsilon_2$$

where v is the average of the observed values, ε_1 and ε_2 are the orthogonal functions of d given by $\varepsilon_1 = d - \bar{d}$; $\varepsilon_2 = \varepsilon_1^2 - \frac{n^2{}_1 - 1}{12}$

and b_1 and b_2 are constants given by the usual formulæ, namely

$$b_1 = \frac{S\ (\varepsilon_1\ v)}{S\ (\varepsilon_1^2)}$$

$$\text{and } b_2 = \frac{S\ (\varepsilon_2\ v)}{S\ (\varepsilon_2^2)}$$

It will be clear that γ_2 is identical with b_2 and $\beta = b_1 - 2\bar{d}\,b_2$. The variances of b_1 and b_2 are clearly independent of each other, being given by

$$V(b_1) = \frac{\sigma^2}{S\ (\varepsilon_1^2)}$$

$$V(b_2) = \frac{\sigma^2}{S\ (\varepsilon_2^2)}$$

where σ^2 is the variance of v. The variance of the optimum dose is clearly the variance of $\frac{q-b_1}{2b_2}$. On differentiating and squaring it will be found to be

$$\frac{\sigma^2}{b_2^2}\left\{\frac{(\hat{d}-\bar{d})^2}{S\ (\varepsilon_2^2)} + \frac{1}{4}\frac{1}{S\ (\varepsilon_1^2)}\right\}$$

The profit to be expected for any given dose of manure is clearly given by the ordinate of the value curve. It follows from what has been given above that its variance is simply the variance of mean $\bar{v}$ *plus* the quantity

$$\sigma^2\left\{\frac{\varepsilon_1^2}{S\ (\varepsilon_1^2)} + \frac{\varepsilon_2^2}{S\ (\varepsilon_2^2)}\right\}$$

SOIL UNIFORMITY TRIALS IN THE PUNJAB, II

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DURING recent years a number of fertility trials have been carried out at various agricultural stations in the Punjab. In the first paper of the series [Lander, Narain and Singh, 1938] the data relating to four soil uniformity test crops grown at the Rawalpindi Agricultural Station were presented. One of the more important conclusions arrived at was the recognition of the fact that soil heterogeneity may be of two types—casual and permanent—and that while the former may vary with the crop and the season, the latter is independent of such factors, and maintains its level under all conditions.

The effects of these permanent differences in the soil fertility of any piece of land can be eliminated by adopting a suitable form of layout which takes into consideration variations in soil fertility of different portions of the land in question. It has been observed, however, that in a number of cases, even after eliminating the effects of these fertility differences, there may still remain differences between the individual plots within a block, which, although due to casual factors, are sometimes responsible for large errors in the experiment. The method of covariance attempts to evaluate the effect of these casual factors when they persist for more than one season.

A study of the literature on this subject shows that very useful results have been obtained by the application of the method of covariance to data from perennial crops. Of late, considerable stress has been laid on the importance of growing soil fertility crops* and very often suggestions have been put forward that in case the relative yields of plots are maintained during succeeding seasons, the application of this method should prove useful in bringing about an appreciable reduction in error even in the case of annual crops. Sanders [1930] was probably the first to take up Fisher's original suggestion and apply the method to data from such crops. The usefulness of the method has subsequently been tested by a number of workers, viz. Verteuil [1934], Summerby [1934], Vaidyanathan [1934], Love [1936], Lander, Narain and Singh [1938] and others. It will be recognized, however, that the data examined

*In this connection reference may be made to the comprehensive list of papers on uniformity trials published by Cochran [1937] under the title *Catalogue of uniformity trial data*.

by most of the above authors are not sufficient to allow of a definite conclusion being arrived at about the usefulness of the method of covariance in the study of annual crops, but, as has been mentioned in the previous paper of this series, considerable data from fertility trials carried out at various agricultural stations in the Punjab are available, which could be used to examine exhaustively the usefulness of the application of the method of covariance in increasing the precision of results obtained from annual crops.

Experimental material

The following table shows the names of stations and of crops grown together with the size of plots and the seasons of growth

Name of station	Plot size (acres)	Crops and years						Remarks
		1929		1930		1931		
		Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	
Sargodha . . .	1/10		Wheat*	Maize**	Wheat			Div. A
			Wheat	*Chari*†	Wheat			" B
		Chari†	Wheat		Wheat			" C
			Wheat	*Chari*	Wheat			" D
		Chari	Wheat		Wheat			" E
Montgomery . .	1/18		Wheat (1932-33)		Wheat (1933-34)	*Chari* (1934)		Sq. 17 Div. A, B, C & D
					Wheat (1931-32)	*Chari* (1932)		Sq. 28 Div. A, B, C & D
Karor . . .	1/20			*Chari*	Wheat		Wheat	
Lyallpur . . .	2/9	*Chari*	Wheat	*Chari*				
Gurdaspur . .	1/10	*Chari*	Gram	*Chari*				
Hansi . . .	1/10			*Chari*		*Chari*		Div. A & B

**Triticum vulgare*
***Zea mays*
†*Andropogon Sorghum*

Examination of data from uniformity trials

In the previous paper, the data from the Rawalpindi Agricultural Station were examined in half a dozen different ways with the object not only of studying soil heterogeneity of the land under trial but also of ascertaining how far the method of covariance could be usefully employed in increasing the precision of the experiment in the case of annual crops. In the present paper, only the coefficients of variation of different blocks have been used as an index of soil heterogeneity. The analyses of variance and covariance have been employed to study the standard error per plot and also to measure the extent to which the precision of the experiment can be increased by a consideration of the data obtained from previous crops.

As has been explained in the first paper of the series, the adjusted variance of the supposed experimental crops can be calculated according to Sanders' [1930] formula.

$$Vyx = \left(Vy - \frac{(Cov\ xy)^2}{Vx} \right) \frac{n}{n-1}$$

where x stands for preliminary yields, y for subsequent yields, *Cov* for covariance and Vyx for variance of y corrected for x. The values for adjusted variances thus obtained have been given in relevant tables. If, however, data of two or more previous crops are available the adujstment necessitates a simultaneous correction for regression of the yields of final crop on those of the previous ones. One of the methods suggested by Sanders [1930] and applied subsequently by Summerby [1934] and Love [1936] is to obtain the average of the yields of each plot in different years expressed as a percentage of their respective mean. These figures are then employed for the analysis of the experimental crop. There is, however, another method suggested by Brady [1935] according to which it is necessary to form a new regression equation which is based on two or more variables as the case may be. As an illustration of the use of this method the various steps leading to the evaluation of the results are discussed in some detail with reference to the yield data from division A at Sargodha given below :—

Yields (mds. per acre) for the three test crops from division A at Sargodha

Block 1			Block 2			Block 3			Block 4		
Wheat 1929-30	Maize 1930	Wheat 1930-31	Wheat 1929-30	Maize 1930	Wheat 1930-31	Wheat 1929-30	Maize 1930	Wheat 1930-31	Wheat 1929-30	Maize 1930	Wheat 1930-31
45·5	85·3	14·3	57·0	71·0	24·3	66·0	82·3	76·5	64·0	121·0	47·0
44·3	84·0	14·5	51·8	46·8	25·8	70·8	169·0	51·5	63·3	109·5	49·5
49·5	90·3	16·8	64·3	82·5	20·0	77·8	184·0	46·8	63·5	115·8	46·0
59·0	85·5	18·8	62·0	88·3	17·5	72·5	162·0	52·0	69·0	136·0	54·3
56·5	82·8	13·8	66·0	88·5	24·3	75·8	125·3	38·5	65·5	139·0	45·0
50·3	79·0	15·8	58·8	83·5	40·3	67·5	99·3	43·5	68·0	135·8	52·8
52·5	81·3	19·8	49·5	76·3	37·5	71·8	115·5	37·8	70·5	160·3	67·8
60·5	73·5	18·3	46·0	87·8	39·0	63·3	99·0	70·8	80·3	144·0	52·3

The analyses of variance and covariance for this division are given below :—

Analyses of variance and covariance for different crops (Sargodha)

Division	Description	Source of variation	Degrees of freedom	Sum of squares	Variance	Test crops	Sum of products	Covariance
A .	I Wheat 1929-30 .	Between blocks	3	1857·55	...	I×II	5866·92	...
		Within blocks	28	1009·75	36·06		—1541·69	55·06
	II Maize 1930 .	Between blocks	3	20698·69	...	II×III	11722·80	...
		Within blocks	28	13343·37	476·55		—845·55	—30·20
	III Wheat 1930-31 .	Between blocks	3	7525·04	...	I×III	3706·12	...
		Within blocks	28	2410·95	86·11		—478·24	—17·08

From the figures given above, the two regression coefficients b_1 and b_2 can be easily calculated with the help of the following equations :—

$$b_1 = \frac{(Vx_2 \times Cov\ x_1 y) - (Cov\ x_1 x_2 \times Cov\ x_2 y)}{Vx_1 \times Vx_2 - (Cov\ x_1\ x_2)^2} \text{ and}$$

$$b_2 = \frac{(Vx_1 \times Cov\ x_2 y) - (Cov\ x_1 x_2 \times Cov\ x_1 y)}{Vx_1 \times Vx_2 - (Cov\ x_1\ x_2)^2}$$

where x_1, x_2 and y stand for the first, the second and the third crop respectively. The values for b_1 and b_2 obtained by substituting the values given in the statement of analyses of variance and covariance above work out to :

$b_1 = -0\cdot4576$ and
$b_2 = -0\cdot0105$

Using these values the variance of adjusted yields in any line in the analysis of variance can be readily obtained by applying the following formula :

$$Vyx_1x_2 = \left\{ Vy - b_1\ (Cov\ x_1y) - b_2\ (Cov\ x_2y) \right\} \frac{n}{n-2}$$

where Vyx_1x_2 is the adjusted variance of the final crop. Substituting the necessary figures in the above formula we obtain

$$Vyx_1x_2 = \left\{ 86\cdot11 - (-0\cdot4576 \times -17\cdot08) - (-0\cdot0105 \times -30\cdot20) \right\} \times \frac{28}{26}$$
$$= 83\cdot98$$

It is to be noted that as two degrees of freedom have been used for calculating the two regression constants b_1 and b_2, the degrees of freedom corresponding to error have to be diminished by 2, leaving in the example cited above only 26 degrees of freedom ascribable to error. Thus the figure for adjusted variance will be 83·98. This change of variance for the third crop from 86·11 to 83·98 indicates that there has been a small increase in the relative precision of the result to the extent of $\frac{86\cdot11}{83\cdot98}$ or 1·0255. The percentage gain in precision will therefore be (1·0255×100)—100 or 2·55. The increase in the accuracy of the experiment is thus only very slight and inappreciable.

The above discussion illustrates how the method of covariance can be applied to adjust the yields of the experimental crop when yield data of three or more crops are available.

As the values of the two regression coefficients b_1 and b_2 have been calculated from the variance and covariance of the three crops, the variance for the adjusted yields in any line in the analysis of variance can be directly worked out by substituting, in the following formula, the corresponding values given in the statement of analyses of variance and covariance already given :—

$$Vyx_1\,x_2 = \left\{ Vy - \frac{(Cov\ x_1y)^2\ Vx_2 - (Cov\ x_2\ y)^2\ Vx_1 - 2\ (Cov\ x_1\ x_2)\ (Cov\ x_1\ y)\ (Cov\ x_2\ y)}{Vx_1\ Vx_2 - (Cov\ x_1\ x_2)^2} \right\} \frac{n}{n-2}$$

It will be seen that in applying the above equation for obtaining the variance of the adujsted yields, the need of calculating the regression coefficients is eliminated. The evaluation of these figures, however, and their use as explained already, supply a useful check on the accuracy of the arithmetic employed.

As different crops were grown at various stations during any one season and under different soil and climate conditions, it is proposed to examine the results for each station separately.

SARGODHA

It will be seen from the statement already given that the trials at Sargodha were carried out in five divisions, each consisting of four blocks of eight plots. The mean yield and coefficients of variation for each block in different sub-divisions are given in Table I.

It will be observed that the yield of wheat following maize or *chari*, with one or two exceptions, is invariably lower than the yield of wheat either preceding any of these two crops or following wheat as in divisions C and E. In other words the yield of wheat following a *kharif* fallow is invariably higher than that which is obtained after a *kharif* crop of maize or *chari*.

Considering the coefficients of variation, it is found that in the case of wheat a high coefficient of variation is generally associated with low mean yields. The wide differences obtained in the values of this constant indicate the lack of any constancy in the fertility of the plots within each block of any division.

The analyses of variance and covariance for different crops grown in each division are given in Table II, which also gives the percentage standard error, regression coefficients, adjusted variance, relative precision of results and the percentage gain in precision resulting from the application of the method of simple and multiple covariance.

The percentage standard errors (Table II) per acre, even after the elimination of soil-fertility differences are sufficiently high, and in the case of the three crops, viz. wheat 1930-31 (A), wheat 1929-30 (C), and *chari* 1929(E), they are much higher than can normally be allowed in field experiments.

The figures for percentage gain in precision obtained by considering different crops vary within wide limits, the values being positive in the case of some crops and negative in that of others. In division D, although all the four values are positive, yet the extent of variation in these values is by no means small. Considering all the divisions, the variation in these values indicates that the anticipated gain in precision is very uncertain, so much so that a loss in precision was recorded in five cases out of a total of 20 examined. Even the application of multiple covariance conferred no special advantage.

MONTGOMERY

The trials at Montgomery were conducted on two pieces of land in squares 17 and 28. There were four divisions in each square, the crops in sq. 17 being wheat-wheat-*chari*, while in square 28 they were wheat and *chari*. The results from these two pieces of land are presented and discussed separately.

Square 17.—The data relating to this piece of land are presented in Tables III and IV. Considering the mean yields of wheat in all the divisions it will be observed that these are higher in the case of the 1932-33 crops than those obtained during the succeeding year. In all cases except two, the high yields are associated with a low coefficient of variation, and *vice versa*. It may further be noted that the yields of wheat in 1933-34, due to very late sowing, are exceptionally low in all the blocks in all the divisions. In the year 1932-33, division

C gave the highest yield of all, otherwise there seems to be a definite fertility gradient from divisions A to D. This is also apparent when we consider the mean yields of wheat in the succeeding year in all the divisions. This fertility gradient, however, is not noticeable when the yields of *chari* in 1934 are considered. Figures for percentage standard errors given in Table IV confirm the conclusion that, in a majority of cases, high standard errors are associated with low mean yields, and *vice versa*. The figures for percentage gain or loss of precision given in the same table corroborate the conclusions drawn from trials at other stations, viz. that there is no appreciable gain in precision by adjusting the yields of an experimental crop with reference to those of the previous non-experimental ones. In the present case when the yields of crop II in division A are corrected for those of crop I, there is a gain in precision of 43 per cent, but this gain in precision in divisions B, C and D comes to only 7, 11 and 3 per cent respectively, which is not commensurate with the time, labour and expense involved in conducting fertility trials. In none of the remaining cases is there any gain in precision except in the case of the crop III in division A when its yield is corrected with reference to that of crop II, but this gain in precision is nominal and inappreciable, being only 0·45 per cent.

Square 28.—The yields of wheat obtained from this piece of land were very high and almost equal to those for the succeeding *chari* crop (Table V). The coefficients of variation for wheat in different divisions vary between 2 and 11·5 and therefore the standard error for this crop (Table VI) which varies between 4·41 and 8·06 is one of the lowest found during these trials anywhere. Similarly, the coefficients of variation for the succeeding *chari* crop, although higher than those of wheat, are fairly uniform in different divisions. Considering the results for relative precision it seems that except for division A, the percentage gain in precision, when the yields of crop II are corrected for those of crop I, is positive in all cases, being about 12 per cent in division C and 29 per cent in divisions B and D. These positive figures, however, are of no practical significance.

Karor (Muzaffargarh district)

At this place three crops were grown in six blocks of six plots each. The mean yields and coefficients of variation are given in Table VII, and it will be seen that here also the yield of wheat following a *kharif* fallow is much higher than that following a *chari* crop during *kharif*. The coefficients of variation in the case of wheat in five cases out of six are greater where the yields are low. Analyses of variance and covariance and the figures for relative gain in precision are given in Table VIII. It will be seen here that not only is there no uniformity in the figures for gain in precision, but even the extent of this gain indicated by positive figures in this table is very small.

Lyallpur

The data for this station are presented in Tables IX and X. The values for coefficients of variation in all the blocks at this station vary between 6 and 23 except in the case of the last two crops, viz. wheat and *chari* in block 1. In block 1 the figures for wheat and *chari* are as high as 40 and 37 respectively. The standard error for the two *chari* crops is nearly 13, while for wheat it is 17. The values for percentage gain in precision resulting after adjustment of the

yields of crop III on the basis of those of crop II, and crops I and II taken together, are very high, the relative precision being more than double.

GURDASPUR

The data for this station are presented in Tables XI and XII. One peculiar feature of these trials was that a legume crop, viz. gram, intervened between the two *kharif* crops of *chari*, and the coefficients of variation for the gram crop, in five cases out of six, are the highest. Even the percentage standard error for this crop (Table XII) is more than two to three times that of *chari*. It was expected that yields of *chari* after gram would benefit by fixation of nitrogen brought about by the latter crop, but these yields, following the gram crop, were invariably lower than the yields from the *chari* crop preceding it. This may be due to seasonal factors which, during the two months that the land remained fallow, might have exercised an adverse effect on the conservation of nitrogen brought about by the previous crop.

No practical gain in precision resulted in any case by the application of the method of covariance.

HANSI

The two crops for which data at this station are available were both *chari*. The yields of the second crop in both the divisions (Table XIII) which followed a *rabi* fallow were lower than those of the first crop. This shows that the intervening fallow has not been able to raise the standard of fertility to its original level, and to raise *chari* after *chari* without manuring is not likely to be an economic proposition. The standard errors for the four crops (Table XIV) in the two divisions vary between 11 and 13 and are of the lowest. There has been no gain in precision in division A by the application of covariance, while division B shows a gain of about 50 per cent.

CONCLUSIONS

Before drawing any general conclusions from the data presented above, attention must be drawn to the high standard errors generally met with in the yield from these experiments. Except in the case of division B at Sargodha where the standard error varies between 6·8 and 13·6 and of all the four divisions in square 28 at Montgomery where this variation lies between 4·4 and 12·4 and at Hansi with figures less than 13, the standard errors in the remaining cases are not only very high but also show wide variations even in the same division. For example, in the case of division C at Sargodha, the error varies between 9·5 and 32·1 and at Montgomery in square 17, division B the variation is between 15·7 and 52·7. Similarly at Gurdaspur the variations are between 8·5 and 29·0. These high figures seem to indicate a high degree of soil heterogeneity or a low standard of cultivation or both.

During the examination of the data it was found that the variance due to 'between block' was invariably many times greater than that due to within blocks, thereby showing that the forms of layout adopted were efficient. From theoretical considerations, it would seem that an increase in the size of blocks would bring about an increase in error, since under these conditions, the elimination of fertility differences due to blocks will not be adequate. In these trials blocks of different sizes varying from 0·3 to 1·5 acres were employed

at different places. However, no consistent relationship between the size of the block and the error per plot is noticeable. For instance, at the Montgomery Agricultural Station, the size of the blocks in square 28 is only slightly greater than that in square 17, and yet in the former case, the standard error per plot is much higher than that obtained in the latter case. Similarly, in division B at Hansi, the block size is 9/10 of an acre as against 8/10 of an acre at Sargodha, but the standard error per plot is much higher in the latter case. At Lyallpur and Karor also the standard errors are of the same order although the size of the blocks at Lyallpur is five times the size of those at Karor.

Considering the increase in precision resulting from the application of the method of covariance, it will be seen that in all 54 cases have been examined ; 42 of these are of simple covariance where the yields of a crop are adjusted according to the yields of one previous crop and the remaining 12 are cases of multiple covariance where the yields of the third crop are adjusted with reference to those of the first and second conjointly. Of the 42 cases of covariance, positive values have been obtained in 23 cases and negative in 19. Of these 23 positive values, however, the gain in precision can be said to be appreciable only in four cases, the actual figures for such percentage gain being 91, 115, 113 and 49, which cannot be regarded as commensurate with the time and labour spent. Of the 12 cases of multiple covariance 7 are positive, and of these only three gave appreciable increase in precision, the actual figures being 53, 106 and 115.

The data presented in this paper demonstrate conclusively that no useful gain in precision is likely to result by conducting a preliminary uniformity trial. The results obtained further show that the value for the gain in precision obtained by the application of simple covariance is not likely to be enhanced if, instead of one, two uniformity crops are taken. The time and labour spent in raising these crops during a uniformity trial are thus in no way justified. Consequently on grounds of precision alone, the conduct of preliminary trials in the case of annual crops cannot be recommended. The fact that these delay the experimental results by at least one year is an additional argument against such trials.

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TABLE I

Mean yield in mds. per acre and coefficient of variation of each block in different years (Sargodha)

Division	Crop and year	Block 1 Mean yield	Block 1 Coefficient of variation	Block 2 Mean yield	Block 2 Coefficient of variation	Block 3 Mean yield	Block 3 Coefficient of variation	Block 4 Mean yield	Block 4 Coefficient of variation	Remarks
A	Wheat 1929-30	52·3	11·47	57·1	11·68	70·2	6·98	68·0	8·43	4 blocks of 5 plots each
	Maize 1930	32·7	6·03	78·1	18·03	129·6	28·98	132·7	12·44	
	Wheat 1930-31	16·5	14·49	28·6	31·43	52·2	27·45	51·8	14·07	
B	Wheat 1929-30	42·0	17·43	46·0	14·33	59·6	12·74	51·6	10·16	
	Chari 1930	148·6	8·39	157·9	14·42	241·5	9·94	194·0	11·45	
	Wheat 1930-31	16·5	13·76	28·6	31·43	52·2	26·88	51·8	14·01	
C	*Chari* 1929	134·8	3·02	130·1	12·91	78·5	14·04	81·0	11·88	
	Wheat 1929-30	29·1	12·10	42·3	36·03	14·0	11·86	12·9	11·32	
	Wheat 1930-31	70·3	10·01	53·9	5·36	68·3	11·88	67·9	8·06	
D	Wheat 1929-30	101·5	6·12	86·1	5·64	111·3	11·34	94·3	11·98	
	Chari 1930	83·7	9·43	88·3	18·20	101·8	19·72	96·3	14·64	
	Wheat 1930-31	8·6	3·60	8·9	4·72	13·5	18·15	12·6	8·97	
E	*Chari* 1929	89·0	25·83	122·8	33·50	124·4	9·70	114·9	12·85	
	Wheat 1929-30	15·5	13·29	13·4	16·79	12·6	7·62	11·1	17·57	
	Wheat 1930-31	39·9	20·07	52·4	11·22	83·8	11·92	65·2	17·33	

TABLE II

Analyses of variance and covariance for different crops (Sargodha)

Division	Due to	Analysis of original yields: Degrees of freedom	Crops				Adjustment by covariance: II Corrected for I	III Corrected for II	III Corrected for I	III Corrected for I & II
			Wheat 1929-30 I	Maize 1930 II	Wheat 1930-31 III					
			Mean sq.	Mean sq.	Mean sq.	Coefficient of regression (b) .	+1·5270	—0·0634	—0·4737	b_1=—0·4576 b_2=—0·0105
	Error	28	36·06	476·55	86·11	Adjusted variance . .	407·00	87·31	80·90	83·98
			Covariance I×II	Covariance II×III	Covariance I×III					
A . .	Error	28	+55·06	—30·20	—17·08	Relative precision . .	1·1710	0·9862	1·0643	1·0255
	Percentage standard error		9·69	20·63	24·88	Percentage gain or loss of precision	+17·10	—1·38	+6·43	+2·55
			Wheat 1929-30 I	*Chari* 1930 II	Wheat 1930-31 III	Coefficient of regression (b) .	—0·1688	+0·0598	+0·1321	b_1=+0·1428 b_2=+0·0623
			Mean sq.	Mean sq.	Mean sq.					
	Error	28	45·86	440·49	6·31	Adjusted variance . .	455·43	4·92	5·71	4·10
			Covariance I×II	Covariance II×III	Covariance I×III					
B . .	Error	28	—7·74	+26·33	+6·06	Relative precision . . .	0·9671	1·2825	1·1051	1·5337
	Percentage standard error		13·59	11·32	6·84	Percentage gain or loss of precision	—3·29	+28·25	+10·51	+53·78
			Chari 1929 I	Wheat 1929-30 II	Wheat 1930-31 III	Coefficient of regression (b) .	+0·9255	+0·1120	+0·2369	b_1=+0·2311 b_2=+0·0632
			Mean sq.	Mean sq.	Mean sq.					
	Error	28	142·50	62·40	38·33	Adjusted variance .	63·44	38·94	31·45	32·40

TABLE II—*contd.*

Division	Due to	Analysis of original yields: Degrees of freedom	Crops				Adjustment by covariance: II Corrected for I	III Corrected for II	III Corrected for I	III Corrected for I & II
			Covariance I×II	Covariance II×III	Covariance I×III					
C .	Error	28	+13·19	+6·99	+33·76	Relative precision . .	0·9836	0·9843	1·2188	1·1830
	Percentage standard error		11·25	32·11	9·49	Percentage gain or loss of precision	—1·64	—1·57	+21·88	+18·30
			Wheat 1929-30 I	*Chari* 1930 II	Wheat 1930-31 III	Coefficient of regression (b) .	+1·1495	+0·0108	+0·0924	$b_1=+0\cdot1587$ $b_2=-0\cdot0577$
			Mean sq.	Mean sq.	Mean sq.					
	Error	28	86·83	231·20	2·50	Adjusted variance . .	120·76	1·16	1·82	1·48
			Covariance I×II	Covariance II×III	Covariance I×III					
D .	Error	28	+99·82	+2·50	+8·02	Relative precision . .	1·9145	2·1551	1·3736	1·6892
	Percentage standard error		9·45	16·45	14·59	Percentage gain or loss of precision	+91·45	+115·51	+37·36	+68·92
			Chari 1929 I	Wheat 1929-30 II	Wheat 1930-31 III	Coefficient of regression (b) .	—0·0273	+0·6657	+0·1486	$b_1=+0\cdot1935$ $b_2=+1\cdot6444$
			Mean sq.	Mean sq.	Mean sq.					
	Error	28	647·60	3·50	81·61	Adjusted variance . .	3·13	83·02	69·80	63·71
			Covariance I×II	Covariance II×III	Covariance I×III					
E .	Error	28	—17·70	+2·33	+96·22	Relative precision . .	1·1192	0·9830	1·1692	1·2809
	Percentage standard error		22·58	14·17	14·98	Percentage gain or loss of precision	+11·92	—1·70	+16·92	+28·09

TABLE III

Mean yield in mds. per acre and coefficient of variation of each block in different years (Montgomery, Square 17)

Division	Crop and year	Blocks 1		2		3		4		5		6		Remarks
		Mean yield	Coeffi-cient of varia-tion	Mean yield	Coeffi-cient of varia-tion	Mean yield	Coeffi-cient of varia-tion	Mean yield	Coeffi-cient of varia-tion	Mean yield	Coeffi-cient of varia-tion	Mean yield	Coeffi-cient of varia-tion	
A .	Wheat 1932-33 .	71·4	16·62	54·0	11·93	56·4	7·18	53·0	6·40	60·0	7·82	59·8	7·58	
	Wheat 1933-34 .	29·2	24·38	35·0	18·86	13·8	26·81	18·2	21·43	18·4	21·96	16·6	28·74	
	Chari 1934 . .	124·2	21·16	97·8	26·21	93·8	10·10	84·0	11·39	90·8	19·40	93·2	8·29	
B .	Wheat 1932-33 .	57·2	15·32	50·8	·28	46·6	3·91	36·8	13·37	31·4	13·82	36·2	8·15	6 blocks of 5 plots each
	Wheat 1933-34 .	19·4	44·12	16·2	44·20	11·8	18·39	10·2	10·79	9·2	32·06	8·4	13·57	
	Chari 1934 . .	58·6	14·86	18·6	52·10	27·4	69·67	66·0	22·29	70·8	19·70	93·2	16·73	
C .	Wheat 1932-33 .	90·2	10·24	78·8	5·77	67·2	7·47	55·0	12·93	54·6	8·26	60·6	4·75	
	Wheat 1933-34 .	13·6	24·19	10·8	21·11	7·2	20·56	6·6	23·03	8·2	41·70	7·4	38·92	
	Chari 1934 . .	81·2	10·79	82·4	10·97	43·0	41·57	15·8	57·90	41·6	48·72	106·0	12·15	
D .	Wheat 1932-33 .	44·8	22·39	45·2	14·72	33·8	8·97	32·0	17·69	27·6	15·91	33·6	6·84	
	Wheat 1933-34 .	10·8	40·56	8·6	22·10	10·0	25·50	11·8	33·05	12·6	7·06	7·2	6·25	
	Chari 1934 . .	84·2	6·79	68·8	11·79	72·6	10·19	62·8	28·43	60·6	26·26	123·2	28·60	

TABLE IV

Analyses of variance and covariance for different crops (Montgomery, Square 17)

Division	Due to	Analyses of original yields: Degrees of freedom	Analyses of original yields: Wheat 1932-33 I	Analyses of original yields: Wheat 1933-34 II	Analyses of original yields: *Chari* 1934 III		Adjustment by covariance: II corrected for I	Adjustment by covariance: III corrected for II	Adjustment by covariance: III corrected for I	Adjustment by covariance: III corrected for I & II
	Error	24	Mean sq. 42·05	Mean sq. 27·00	Mean sq. 316·60	Coefficient of regression (b)	—0·4611	—0·7341	—0·0357	b_1 = —0·5594 b_2 = —1·1358
A.	Error	24	Covariance I × II —19·39	Covariance II × III —19·82	Covariance I × III —1·50	Adjusted variance Relative precision	18·85 1·4324	315·18 1·0045	330·31 0·9585	319·94 0·9896
	Percentage standard error		15·36	33·34	25·60	Percentage gain or loss of precision	+43·24	+0·45	—4·15	—1·04
	Error	24	Mean sq. 24·23	Mean sq. 23·38	Mean sq. 156·40	Coefficient of regression (b)	+0·3207	+0·3614	+0·2200	b_1 = +0·1165 b_2 = +0·3227
B.	Error	24	Covariance I × II +7·77	Covariance II × III +8·45	Covariance I × III +5·33	Adjusted variance Relative precision	21·80 1·0725	160·02 0·9774	161·98 0·9656	166·98 0·9366
	Percentage standard error		15·65	52·67	30·27	Percentage gain or loss of precision	+7·25	—2·26	—3·44	—6·34
	Error	24	Mean sq. 35·03	Mean sq. 6·75	Mean sq. 190·01	Coefficient of regression (b)	+0·1644	+0·5378	+0·3546	b_1 = +0·3096 b_2 = +0·2736
C.	Error	24	Covariance I × II +5·76	Covariance II × III +3·63	Covariance I × III +12·42	Adjusted variance Relative precision	6·05 1·1157	196·24 0·9683	194·68 0·9760	202·02 0·9406
	Percentage standard error		12·23	40·63	31·24	Percentage gain or loss of precision	+11·57	—3·17	—2·40	—5·94
	Error	24	Mean sq. 35·11	Mean sq. 7·63	Mean sq. 327·93	Coefficient of regression (b)	+0·1242	—0·6160	—0·3159	b_1 = +0·4223 b_2 = —0·8573
D.	Error	24	Covariance I × II +4·36	Covariance II × III —4·70	Covariance I × III +11·09	Adjusted variance Relative precision	7·40 1·0311	339·16 0·9821	338·54 0·9687	348·27 0·9416
	Percentage standard error		22·98	37·80	32·23	Percentage gain or loss of precision	+3·11	—1·79	—3·13	—5·84

TABLE V

Mean yield in mds. per acre and cœfficient of variation of each block in different years
(Montgomery, Square 28)

Division	Crop and year	Block 1 Mean yield	Block 1 Coefficient of variation	Block 2 Mean yield	Block 2 Coefficient of variation	Block 3 Mean yield	Block 3 Coefficient of variation	Block 4 Mean yield	Block 4 Coefficient of variation	Block 5 Mean yield	Block 5 Coefficient of variation	Block 6 Mean yield	Block 6 Coefficient of variation	Remarks
A	Wheat 1931-32	108·6	4·78	107·6	4·85	113·6	4·68	117·6	4·88	102·3	4·85	105·4	2·18	
	Chari 1932	108·4	8·47	93·9	11·64	108·0	18·42	129·4	9·23	101·7	12·56	102·1	9·38	
B	Wheat 1931-32	78·7	10·75	99·1	6·12	103·9	4·60	105·4	6·00	98·0	5·31	106·1	6·04	
	Chari 1932	100·3	7·76	93·0	16·11	100·4	11·70	117·4	13·33	110·1	13·83	121·3	10·88	
C	Wheat 1931-32	99·7	5·32	85·1	5·73	78·0	11·44	89·9	9·30	100·6	6·54	115·0	8·88	
	Chari 1932	110·7	14·84	106·6	9·50	90·7	8·19	106·4	13·84	110·9	3·70	132·4	9·44	
D	Wheat 1931-32	104·0	6·26	97·3	5·56	93·4	7·76	102·4	4·75	111·4	6·85	112·6	3·80	
	Chari 1932	100·3	13·86	99·1	5·42	88·4	14·75	90·7	10·37	113·6	4·80	127·0	7·64	

TABLE VI

Analyses of variance and covariance for different crops
(Montgomery, Square 28)

Division	Due to	Analysis of original yields: Degrees of freedom	Wheat 1931-32 I Mean square	*Chari* 1932 II Mean square	Covariance I × II		Adjustment by covariance: Coefficient of regression (*b*)	Adjusted variance	Relative precision	Percentage gain or loss of precision
A	Error	36	24·22	166·24	+2·67	II corrected for I	+0·1103	170·69	0·9739	—2·61
	Percentage standard error		4·41	12·01						
B	Error	36	39·88	176·42	+41·58	Do.	+1·0430	136·87	1·2890	+28·90
	Percentage standard error		6·31	12·40						
C	Error	36	58·20	136·25	+32·54	Do.	+0·5591	121·43	1·1220	+12·20
	Percentage standard error		8·06	10·65						
D	Error	36	37·40	146·98	+36·80	Do.	+0·9844	113·94	1·2900	+29·00
	Percentage standard error		5·95	11·75						

Table VII

Mean yields in maunds per acre and coefficient of variation of each block in different years

(Karor, Muzaffargarh district)

Crop and year	Blocks												Remarks
	1		2		3		4		5		6		
	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	
Chari 1930	63·70	12·27	113·80	7·94	123·80	12·83	140·20	14·73	112·30	7·74	71·50	27·57	
Wheat 1930-31	20·83	20·96	22·42	12·88	33·00	30·01	22·75	30·20	20·33	9·41	18·33	16·51	Six blocks of six plots each
Wheat 1931-32	66·00	12·57	66·00	10·14	94·00	10·59	67·33	13·50	58·67	16·93	50·67	14·05	

Table VIII

Analyses of variance and covariance for different crops

(Karor)

Due to	Analysis of original yields					Adjustment by covariance			
	Degrees of freedom	*Chari* 1930 I	Wheat 1930-31 II	Wheat 1931-32 III		II corrected for I	III corrected for II	III corrected for I	III corrected for I×II
		Mean sq.	Mean sq.	Mean sq.					
Error	30	336·69	30·93	74·00	Coefficient of regression (b)	+0·0020	+0·4746	+0·0643	b_1 = +0·0633 b_2 = +0·4733
		Covariance I×II	Covariance II×III	Covariance I×III	Adjusted variance	31·98	69·31	75·08	70·37
Error	30	+0·66	+14·68	+21·64	Relative precision	0·9671	1·0677	0·9856	1·0516
Percentage standard error		17·62	16·85	12·82	Percentage gain or loss of precision	—3·26	+6·77	—1·44	+5·16

TABLE IX

Mean yield in mds. per acre and coefficient of variation for each block in different years

(Lyallpur)

Crop and year	Blocks												Remarks
	1		2		3		4		5		6		
	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	
Chari 1929	162·3	6·89	192·9	13·77	160·1	10·69	221·9	14·01	171·1	12·06	200·4	13·58	6 blocks of 7 plots each.
Wheat 1929-30	28·3	40·35	22·8	22·81	39·6	15·15	42·0	13·57	50·6	12·39	46·0	15·94	
Chari 1930	240·1	37·08	198·1	21·84	242·9	9·32	258·3	9·91	255·4	9·01	202·1	8·86	

TABLE X

Analyses of variance and covariance for different crops

(Lyallpur)

Due to	Analysis of original yields					Adjustment by covariance			
	Degrees of freedom	*Chari* 1929 I	Gram 1929-30 II	*Chari* 1930 III		II corrected for I	III corrected for II	III corrected for I	III corrected for I&II
		Mean sq.	Mean sq.	Mean sq.					
Error	36	542·80	53·31	1970·95	Coefficient of regression (b)	+0·0945	+4·4865	+0·1907	$b_1 = -0{\cdot}1503$ $b_2 = -0{\cdot}0104$
		Covariance I×II	Covariance II×III	Covariance I×III	Adjusted variance	49·84	923·22	2006·96	916·04
Error	36	+51·31	+239·21	+103·52	Relative precision	1·0696	2·1349	0·9821	2·1516
Percentage standard error		12·61	17·06	13·34	Percentage gain or loss of precision	+6·96	+113·49	—1·79	+115·16

TABLE XI

Mean yield in mds. per acre and coefficient of variation of each block in different years

(Gurdaspur)

Crop and year	Blocks												Remarks
	1		2		3		4		5		6		
	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	
Chari 1929	110·4	7·12	128·5	9·60	183·7	9·10	175·9	5·13	157·7	7·98	151·6	10·60	6 blocks of 11 plots each.
Gram 1929-30	37·6	25·37	58·7	16·80	46·5	23·78	44·5	41·66	31·1	29·07	11·8	23·65	
Chari 1930	74·4	28·17	58·3	12·52	147·4	8·58	133·4	8·13	112·3	9·59	85·3	18·14	

TABLE XII

Analyses of variance and covariance for different crops

(Gurdaspur)

Due to	Analysis of original yields					Adjustment by covariance			
	Degrees of freedom	*Chari* 1929 I	Gram 1929-30 II	*Chari* 1930 III		II corrected for I	III corrected for II	III corrected for I	III corrected for I & II
		Mean sq.	Mean sq.	Mean sq.					
Error	60	165·23	123·98	187·61	Coefficient of regression (b)	+0·0645	—0·1775	—0·1496	b_1 = —0·1503 b_2 = +0·0104
		Covariance I×II	Covariance II×III	Covariance I×III	Adjusted variance	125·37	190·78	187·02	190·23
Error	60	+10·65	—0·22	—24·71	Relative precision	0·9889	0·9834	1·0020	0·9862
Percentage standard error		8·49	28·98	13·46	Percentage gain or loss of precision.	—1·11	—1·66	+0·20	—1·38

TABLE XIII

Mean yield in mds. per acre and coefficient of variation of each block in different years

(Hansi)

Division	Crop and year	Blocks 1 Mean yield	1 Coefficient of variation	2 Mean yield	2 Coefficient of variation	3 Mean yield	3 Coefficient of variation	4 Mean yield	4 Coefficient of variation	5 Mean yield	5 Coefficient of variation	6 Mean yield	6 Coefficient of variation	7 Mean yield	7 Coefficient of variation	8 Mean yield	8 Coefficient of variation	9 Mean yield	9 Coefficient of variation	Remarks
A	*Chari* 1930	249·3	5·29	255·3	16·50	233·5	8·59	176·5	15·08	20·2	10·43	187·3	6·92							6 blocks of 6 plots each
	Chari 1931	119·3	14·07	113·8	15·06	96·3	17·65	82·2	9·28	87·0	13·60	79·2	12·86							
B	*Chari* 1930	190·9	17·98	150·9	12·98	130·1	16·00	159·4	8·61	157·3	8·48	160·2	7·53	184·7	10·88	183·7	6·17	186·6	4·11	
	Chari 1931	87·3	12·52	82·8	12·79	83·7	13·74	95·8	18·78	108·7	6·59	80·6	8·19	88·9	13·37	90·3	10·01	96·6	11·68	9 blocks of 0 plots each

TABLE XIV

Analyses of variance and covariance for different crops

(Hansi)

Division	Due to	Analysis of original yields: Degrees of freedom	*Chari* 1930 I Mean square	*Chari* 1931 II Mean square	Covariance I×II		Adjustment by covariance: Coefficient of regression (*b*)	Adjusted variance	Relative precision	Percentage gain or loss of precision
A	Error	30	618·99	155·57	+23·16	II corrected for I	+0·0374	160·00	0·9724	—2·76
	Percentage standard error		12·87	12·95	...					
B	Error	72	344·30	125·85	+55·23	Do.	+0·1604	118·64	1·4930	+49·30
	Percentage standard error		11·11	11·27	...					

PROBLEMS OF SUGARCANE PHYSIOLOGY IN THE DECCAN CANAL TRACT

III. THE ROOT-SYSTEM

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(With Plates XV and XVI)

Introduction

THE plant itself is after all the best indicator of the biotic condition in the soil, and plant methods are slowly replacing chemical methods in these biotic investigations. Among the different organs of the plant, roots are the means by which the plant is brought ' into gear ' with the soil, and any attempt at improvement in the soil conditions for securing the highest possible yields either by cultivation, manuring or irrigation should aim at increasing the activity of roots, which are the principal agents for supplying water and nutrients for the growth of the crop. The study of the development of the root-system should thus form an important part in any biotic investigation, and more so in the case of sugarcane in the Deccan Canal tract, as its cost of cultivation is very high. We have, therefore, given it its due share of importance in our various investigations and these results are discussed in the following pages.

Historical

In the study of the root-system of sugarcane, Venkatraman [1922], Venkatraman and Thomas [1924, 1929], and Thomas [1927] may be said to be the pioneers, who by rather ingenious methods differentiated between the functions of the two types of roots, viz. (1) sett roots developing from the root eyes of the planted sett, and (2) shoot roots growing from the shoot. According to them, both types of roots are essential for normal development of cane. Sett roots are temporary, being needed for germination and growth of the bud ; but once shoot roots are established, these take over the function of supplying cane with water and mineral salts. These workers are also responsible for much of the earlier work on the development of the root-system from early stages to maturity both in pots as well as directly in the field in the normally planted crop. In the latter case, a pit is either dug vertically down the edge of the plant and roots in a specified thickness of soil extending from the stool to the right and left are carefully dissected out, or a pit is dug on one side of the

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plant, thin iron rods are inserted through the breadth of the interposed soil, and roots are then freed from the soil. In both the cases, according to them, the system can be conveniently studied and photographed.

During recent years much research has been carried out on quantitative basis on the development of roots in Hawaii [Lee and coworker, 1926, 1927, 1928, Weller, 1928, 1930 ; Alexander, 1928 ; Wolters, 1929], Cuba [Jensen, 1931], Java [Kulescha, 1931], Trinidad [Hardy, 1933], Mauritius [Evans, 1934, 1935, 1937, 1939] and Barbados [Stevenson, 1937]. Methods of root dissection as followed by these various workers can be differentiated as follows :—

(1) The 'box method' with horizontal wire netting placed between the boxes and the soil filled in those layer by layer as developed by Venkatraman and Thomas [1924].

(2) The 'direct examination method' of Weaver [1926] which consists in digging deep trenches at such a distance away from the stools as to leave the roots undisturbed in the block of soil encompassed by the trenches. Roots are then carefully freed from the soil either by dissection or washing with water starting with the upper layer, and from the distribution of the roots, plans of the root-system are drawn to scale.

(3) The 'block method' of Rogers which consists in marking a square area of ground round the stool sufficiently large to enclose all the roots by first obtaining an indication of the root-system by preliminary examination of the stool if necessary. The square is divided into four quarters and each of these is subdivided into areas of one foot square. Standing from outside the square, each square foot is examined in detail to a depth of six inches and the position of the roots is marked accurately to the scale on graph paper. Similar procedure is followed for the next six inches and so on until the whole root-system is dissected out.

(4) The 'trench method' as developed by Evans [1935]. This involves working a trench to a depth of one foot at a suitable distance from stools to be examined. The side of the trench is worked towards the stool for a few inches with hand picks and all the roots entering into the trench are marked to scale on graph paper. The trench is then widened to two feet and deepened to two feet and the roots similarly exposed. The trench is thus widened by successive foot widths with an increase in depth of one foot for each such increase in width.

(5) The 'soil core method' of Hardy [1933] which consists of taking cores of soil three inches in diameter, two to three feet deep and 4, 11 and 18 inches radially from the centre of the stool ; and the quantity of roots are estimated from these cores.

The results of studies thus conducted by various workers can be summarized as follows :—

(1) Soil texture greatly affects root growth, the development of roots being better in well-drained soils than in badly drained ones [Lee, 1926 ; Alexander, 1928 ; Venkatraman and Thomas, 1929 ; Jensen, 1931]. Kulescha [1931], who studied the behaviour of POJ 2878 in six soil types by the direct examination method, has concluded that the character of the root-system is markedly affected by the type of soil as regards distribution, number, length of roots and the maximum depth to which they descend. Hardy [1933], who

did his studies with the soil core method, however, does not find the effect of the soil texture to be very marked.

(2) The quantity of roots is generally increased by the application of fertilizers. Wolters [1929] has, however, found a marked correlation between root growth and crop growth irrespective of the fertilizer treatment or irrigation under the same soil conditions. This would appear to show that fertilizers do not exert a specific effect on the root-system alone, this beneficial effect being reflected on the stool as well. Venkatraman and Thomas [1929] also find a positive correlation of the above-ground portion with the growth vigour of the shoot roots. On the other hand, Evans [1938] does not find any close relationship between the development of the roots and the above-ground parts. Hardy [1933] also maintains that there is no simple relationship between root weights and crop weights.

(3) Soil moisture has an important effect on the root-system, adequate soil moisture favouring surface rooting and low soil moisture deep rooting [Stevenson, 1937]. Venkatraman and Thomas [1929] find the effect of irrigation with saline water to be adverse to root development.

(4) There is a marked variation in the root-system of the different varieties, and Venkatraman [1929] has emphasized the necessity of working out the typical root-system of each variety as it would be a good guide in manurial and cultural operations. Evans [1935] has differentiated between three types of roots: (*a*) superficial roots, (*b*) buttress roots, and (*c*) the rope system, the two latter going deep into the soil. In noble canes, superficial roots are well developed, while canes containing wild blood develop more of the deeper roots. He has further found the shoot/root ratio to be different for different varieties. Some varieties make a good aerial growth with a mediocre root-system, while others have an extensive root-system with similar or even less vigorous top growth.

Method used in the present investigation

During the course of our investigations it was observed that application of such artificial methods as planting in: (1) pots, (2) rings, or (3) in isolated positions in the field with a free space all round the stool induced the development of a root-system differing greatly from that of the normally planted crop. In pots, although the soil was compacted layer by layer as occurring in the field, the root-system of POJ 2878 permeated in all the three feet depth of soil, while under field conditions it was restricted to the first two feet depth of the same soil. So also in the case when buds were planted in isolated position, the spread of the root-system was almost uniform all round the stool. Under normal planting, this spread is mainly on two sides of the stool, as there is very little space between the two germinated buds in the same row to permit root development in between them. We therefore eschewed all these artificial methods for the quantitative studies. Among the methods considered to be suitable for the examination of the root-system *in situ* Hardy's method was found to be inadequate for giving a true picture of the system, while other methods, such as the 'block method', the 'direct examination method' or the 'trench method', were found to be too laborious and time-consuming. Besides, the adoption of these methods tends to a great wastage of the plant material owing to the necessity of digging trenches either all round the stool

under examination or on its opposite sides. These methods were thus considered impracticable in application during the development of the crop in the experimental layout of varieties, manuring, irrigation, etc. In the comparative studies of the various methods in vogue, digging of a pit vertically down the edge of the stool and exposing the root-system by washing the soil in a specified zone was found to be the best. It leads to the least wastage of the plant material as it practically does not disturb other plants. It is very rapid, two labourers being capable of exposing roots of eight to ten stools per day. It is also quite accurate for quantitative work if certain precautions as enumerated below are taken.

In the Deccan Canal tract, cane setts are planted in furrows four feet apart with 10,000 three-budded setts per acre. Taking the germination to be about 70 to 80 per cent, germinated buds will have only a space of about six inches in between them in the same row for the development of roots. Thus a thickness of soil, equal to six inches, will contain practically all the roots of the stool under examination on its both the right and left sides in the intervening space between the adjoining furrows. A normally developed cane stool, away from the water channel and protected from wind, is selected almost at the end of a row in the treatment under study. One or two stools at the end of the row, which get the advantage of extra space, are removed and a trench is dug about two feet wide and two to three feet deep right across the row extending about $2\frac{1}{2}$ ft. on either side of the selected stool. The soil is then gently washed off by means of a fine spray pump, taking care not to dislodge the roots from their natural position while tracing them (Plate XV, fig. 1). If the soil is too compact, it can be gently loosened with a sharp pointed needle. No difficulty in washing off the soil is experienced, if the soil is kept at its moisture equivalent for about 24 hours before starting root excavations. If the soil is too dry, small clods are formed, which, while being dislodged by the spray, tear away the fine roots. In this soil, the second or the third day after irrigation is found to be the most suitable period from the point of soil moisture. Washing is very easy and no roots—not even the finest ones—are lost in the washing.

The root-system is now ready for taking observations. Counts of the number of roots of different diameters can be then taken and sketches drawn to scale. The root-system can be also conveniently photographed. For quantitative determinations, roots are cut in squares of 6 or 12 in. from the centre of the stool marked out by means of pins, which are passed through an iron frame divided into these squares (Plate XV, fig. 1). These roots are then washed free of soil with water by placing them on a fine meshed sieve, dried in the oven and the dry weights are recorded (Table I).

Canes from which roots are cut are also weighed and samples are kept for the moisture content in order to determine the shoot/root ratio.

General characteristics of the root-system

Immediately after planting, sett roots begin to develop within a week to a fortnight, depending upon the condition of the sett and the atmospheric temperatures. According to Rege and Wagle [1939], minimum temperatures below 50°F. are inhibitive to the activities of the sett, which remains generally

dormant under such conditions. In a three-budded sett, which is commonly used as a planting material in this tract, a gradient in the development of roots from the bottom to the top node is observed, the largest quantity of roots being formed in the case of the bottom node. On the other hand, buds at the middle and top nodes, which sprout earlier, produce more vigorous shoots than the bottom one (Table II). Similarly, in the whole cane, basal nodes produce more profuse roots than apical ones. This is explained by Loeb [1919] by the transfer of inhibitors produced by the topmost buds t wards the base of the stem, leaving the buds at the apex clear of these ; and their downward current has a stimulating action on the development of roots at the nodes below.

TABLE I

Distribution of roots of a cane stool

(Oven-dry weights)

POJ 2878—225 lb. N

Stool weight — 461·6 gm.

$$\frac{\text{Stool weight}}{\text{Root weight}} = 16\cdot 9$$

Stool

gm.	1·66	6·06	8·51	1·74	gm.
		65.9 per cent			
,,	1·51	2·37	3·80	1·63	,,
		34·1 per cent			

(Each square is 1 ft. × 1 ft.)

Total weight —27·28 gm.

TABLE II

Behaviour of three-budded setts during germination

(Average of 6 rows each with 30 three-budded setts)

Variety—POJ 2878

Date of planting	Position of the bud	Oven-dry weight per germinated shoot in gm. at 8 weeks from planting	
		Shoot	Roots
10 Feb. 1937 . .	Bottom	4·78	0·65
	Middle	7·48	0·45
	Top	6·61	0·37
26 Feb. 1937 . .	Bottom	5·43	0·57
	Middle	8·27	0·45
	Top	7·37	0·43

Shoot roots are formed soon after germination and these are generally whiter and thicker than sett roots. They can be, therefore, easily distinguished from the others, which are thinner and more superficial. With the progress in the development of the shoot roots, these sett roots cease to function and soon die. A general idea about the periodical increase in the number of roots, their thickness, lateral spread and depth of penetration from germination to harvest time is given in Table III.

TABLE III

Periodical development of the root-system

(Average of four stools)

Variety—POJ 2878

Period	No. of roots				Total	Depth of penetration in inches	Lateral spread in inches
	Thin (0·5 — 1·0 mm. in dia.)	Medium (1·1—1·5 mm. in dia.)	Thick (1·6 — 2·5 mm. in dia.)	Very thick (2·6 mm. and above in dia.)			
2 months	25	...	10	...	35	9·5	9·0
5½ months (i.e. just before earthing)	20	20	10	...	50	18·0	24·0
7½ months	61	75	19	...	155	24·0	24·0
Harvest time (11 months) .	98	76	65	24	263	28·0	24·0

Before the operation of earthing, roots penetrate through the whole mass of soil in the ridge which contains much of the assimilable nitrogen. The depth of penetration during this period is comparatively less and does not exceed 1½ ft. During the course of earthing, most of the roots in the ridge are pruned and this pruning is considered to be necessary for good growth. This belief is, however, found to be quite untenable by Rege and Wagle [1939] who have shown that for securing good growth, pruning of roots is not an essential prerequisite. Earthing covers two to three nodes depending upon the height of earthing and all these nodes produce roots, thus increasing their number to a great extent. This is also the time when the plant starts its grand period of growth and both the root and shoot activities are at their highest. There is profuse branching of roots at this period with an increase also in their depth penetration. This has, however, never exceeded 36 in. in this soil, inclusive of the earthed-up portion, in spite of diverse treatments.

From the standpoint of the functional behaviour of roots, there does not seem to be any clear differentiation as has been shown by Evans [1935]. No doubt, as the shoot develops and increases in height and weight, the older roots get thicker and thus can afford the plant some support for anchorage. But this cannot be considered to be the only function of these roots as although they do resemble the dead ones, some of them are found to possess living roots in the proximity of their ends, which serve as absorbing agents of nutrients as well.

INFLUENCE OF ENVIRONMENTAL FACTORS

(a) Soil

Soils of the Deccan Canal tract belong to the broad group of *regur* or black cotton soil, which is further classified by Basu and Sirur [1938] into soil types possessing distinct chemical and physical properties. Two of these types are available at this station and the quantitative data of the root behaviour in these types are given in Table IV. The type F has a soil depth of about 18 in. with soft *murrum* substratum, while in the case of type B, the depth of soil varies from 3 to 7 ft. In the latter case, the root studies are, therefore, carried out at two locations, one having a shallower phase (4 ft.) and the other a deeper phase (7 ft.). For convenience, they will be termed B medium and B deep respectively.

It is evident from the above data that the effect of soil type is pronounced both in the root and stool weights, the more so in the case of Pundia than POJ 2878. There is a progressive fall in the weights of roots with the increase in the depth of the soil, and even in the same soil type, the depth seems to be important in determining root behaviour. This effect is quite distinct at the early stages of crop growth, and although weights of shoots have not been taken at this period, inspection of the crop showed it to be poorer in the B deep as against B medium. In the F type, the performance of both roots and shoots has been the best from the start and this is reflected in the final stool weights, which are distinctly superior to those in the other type. General observations in the canal tract would appear to indicate that shallower types are better yielders than deeper ones. The root-system in these shallow types contains a larger number of thin roots which penetrate through the whole soil mass, and further the penetration of roots has been observed even in the *murrum* substratum to a depth of 6 to 9 in. Cultivation is not found to be so important in this as well as in the B medium as in the B deep, wherein after a period of five years of cane growing, a great improvement in the spread of roots was observed in the first two feet depth of soil. This was further confirmed by the quantitative data which showed an increase of 28 per cent in root weights over those in Table IV. No improvement was, however, observed in their depth penetration.

In order to properly evaluate the nature of the influence of these soil types on root growth, it must be clearly understood that sugarcane in this tract is an entirely irrigated crop, receiving waterings at eight to ten days intervals and is generally heavily manured with nitrogenous top dressings, both in the form of oil-cakes and sulphate of ammonia distributed three to four times during the development of the crop. Such limitations as the availability of moisture and nutrients, which are some of the important characteristics of soil types, are therefore masked to a great extent by these treatments. In fact, the good development of such a long-duration crop like sugarcane in shallow types as F can only be possible by the proper maintenance of these two factors. Not only is the water-holding capacity of this soil slightly lower than that of the other type but, owing to the limited soil mass in this type, it contains comparatively less water and nutrients. Studies in capillary movement have also proved it to be practically absent in the *murrum* substratum. The availability of water as well as nutrients for the life processes of

TABLE IV

Influence of soil on the root-system

(Average of four stools)

Soil type	Pundia						POJ 2878					
	Oven-dry wt. of		Per cent distribution of roots				Oven-dry wt of		Per cent distribution of roots			
	Canes in stool (gm.)	Roots (gm.)	Stool wt.† / Root wt.	0-12″	12-24″	24-36″	Canes in stool (gm.)	Roots (gm.)	Stool wt.† / Root wt.	0-12″	12-24″	24-36″
June 1934												
F type	..	15·30	..	75·6	24·4*	..	..	18·75	..	53·8	46·2	..
B medium	..	10·95	..	66·0	34·0	..	..	15·45	..	61·4	38·6	..
B deep	..	6·60	..	65·3	34·7	..	..	12·90	..	57·0	44·0	..
December 1934												
F type	749·0	24·00	31·2	49·5	50·5	..	628·3	35·70	17·6	50·1	49·9	..
B medium	490·5	15·75	31·1	45·2	38·3	16·5	584·8	39·30	14·9	40·7	30·1	29·2
B deep	413·0	15·90	26·0	50·4	35·2	14·4	583·8	21·45	27·2	38·6	35·2	26·2

*The penetration of the roots did not exceed 18 in. in this soil
†Only weight of canes is taken

the crop would, therefore, be ordinarily much less in this type than in the others, and it is only by the system of irrigation and manuring that they are maintained at the proper level. As the root studies in all these soils have been carried out in experiments receiving exactly similar treatments of irrigation and manuring, poorer development of both roots and shoots in B medium and B deep can be attributed mainly to poorer soil aeration. The determination of oxygen at different depths by aloin test has shown it to be about 20 per cent less up to 32 in. as compared to surface 12 in. and 60 per cent less below this depth. The non-occurrence of roots below three feet in the deep soil would be thus explicable. This disinclination of roots to penetrate deeper layers has been observed even after adverse treatments, such as withholding irrigation or manuring. Even subsoiling to a depth of four feet has not been effective. The deficiency of oxygen is, therefore, a potent factor in limiting the distribution of the root-system in this soil. This deficiency appears to be accentuated in the *chopan* soil (alkali soil) in which the root-system is still restricted under quite similar treatments and is present only in the first two feet depth of the soil (Table V).

TABLE V

Root study in chopan *soil*

Variety—Co 413..150 lb. N per acre
(October 1937)
Average of five stools

Soil	Oven-dry wt. of		Per cent distribution of roots			Stool wt. / Root wt.
	Canes in stool (gm.)	Roots (gm.)	0-12″	12-24″	24-36″	
Chopan . .	832	23·6	65·5	34·5	..	35·2
B deep .	780	28·7	47·0	31·1	21·9	27·2

This soil falls genetically under the same B type, but is a degraded one owing to the accumulation of sodium in the colloid complex, which has adversely affected the drainage and has thus increased the deficiency of oxygen in the lower layers.

(*b*) *Soil moisture*

As sugarcane is a totally irrigated crop under Deccan conditions, receiving water at intervals of ten days, the question of the deficiency of soil moisture does not generally arise. On the other hand, there has been a tendency on the part of the cultivators to over-irrigate the crop. Some root studies were, therefore, carried out in an experiment with varying quantities of water and nitrogen and the results are given in Table VI.

TABLE VI

Effect of varying quantities of water and nitrogen on the root-system, December 1937

(Average of 4 stools)

Treatments	Oven-dry wt of		Per cent distribution of roots			Stool wt. / Root wt.
	Canes in stool (gm.)	Roots (gm.)	0-12″	12-24″	24-36″	
POJ 2878						
95″+225 N	696·3	33·4	46·4	38·4	15·2	20·9
130″+225 N	680·4	36·7	51·8	35·0	13·2	18·5
95″+300 N	761·8	37·4	45·3	40·2	14·5	20·4
130″+300 N	905·9	39·9	52·8	39·1	8·1	22·8
Pundia						
95″+225 N	796·0	24·2	66·7	31·1	2·2	32·9
130″+225 N	666·2	23·3	71·1	23·0	5·9	28·6
95″+300 N	835·1	23·6	63·6	24·2	2·2	35·4
130″+300 N	696·0	20·3	72·6	24·2	3·2	34·3

In general, it may be stated that higher watering tends to produce a superficial root-system as could be seen from the higher percentage of roots in the first foot depth of soil in this watering. Further differentiation in the influence of watering is found to be dependent on the varietal characteristics. In the case of POJ 2878, there has been an increase in the total quantity of roots in higher watering with the same manurial dose. The availability of nutrients can be said to be responsible for this increase, as the higher watering is apt to leach down the nutrients to a greater extent than the lower one. On the other hand, Pundia shows a definite tendency towards a fall in the root weights with higher watering. Studies in soil moisture before every irrigation have shown a higher level of moisture in the plots with Pundia than in those with POJ 2878. The irrigational dose in the case of 130 acre-inches may, therefore, be excessive in the case of the former, creating partially waterlogged conditions. Pundia is found to be more susceptible to the deficiency of soil aeration than the other variety. It has been in fact a general experience that Pundia makes very poor growth in heavier types of soil with impeded drainage or under waterlogged conditions, while POJ 2878 does not suffer to the same extent. Weights of stools given in Table VI also clearly indicate that, while in the case of POJ 2878 there has been practically no fall in weight in higher watering with the same manurial dose—and in fact in the case of 300 lb. of nitrogen there has been a definite gain—the reverse is the case with Pundia, both the manurial treatments showing a definite fall in weight in this watering. Final yield data have also shown similar trend in all these treatments. It is thus evident that in the case of higher watering (130 in.) partially waterlogged

conditions are created which have adversely affected the growth of the root-system in the case of Pundia, the result being reflected in the weights of stools also.

Although in the general system of irrigation in vogue, there is little possibility of the crop suffering from shortage of water, some studies on its influence on the root-system have been also carried out both by stopping irrigation till plant showed permanent wilting and secondly by delaying waterings throughout the life of the plant such as 20 days interval as against the usual ten days between two turns. The stoppage of water till permanent wilting was adopted in April in all the three soils for two varieties—Pundia and POJ 2878—when the crop was about three months old, and it took about 24-40 days to attain this stage, depending upon the variety, soil type and depth, the longest period being required in B deep. Immediately on the attainment of this stage, the crop was irrigated with a very slow flow of water twice at an interval of five days and roots were then exposed in this as well as in the normal treatment, which was receiving watering after every ten days. A distinct variation in the root-system in both the treatments was observed, the stoppage of water leading to more lateral spread of roots, which is specially prominent in the case of POJ 2878. This is illustrated in Plate XV, figs. 2 and 3 for one soil only as similar behaviour has been observed in the other soils also. It is quite interesting to note that in spite of such severe treatment there has been very little penetration of roots in the lower depths. The inspection of the root-system showed that at the time of the attainment of permanent wilting by the shoot, all the roots had been dead, and it was only as the result of watering that thick, white roots were produced near the base of the stem which immediately gave an impetus to the growth of the crop, maintaining it at a higher level than the normal treatment. Consequently the plants were able to make up to a great extent for the loss in growth which was caused by the stoppage of water. The yield of millable canes at harvest would, however, depend upon the rate of damage by borers, which is higher during the course of the stoppage of water than in the normal treatment. In the case of POJ 2878, no adverse effect on final yields was observed due to this treatment. These varietal characteristics with the yield data will be dealt with in a separate paper and need not be discussed here.

The other experiment with delayed waterings was conducted in the B deep only and the results of root studies are given in Table VII.

TABLE VII

Effect of delayed watering on root development, December 1938

POJ 2878
(Average of four stools)

Soil	Treatment	Oven-dry wt of		Per cent distribution of roots			$\frac{\text{Stool wt.}}{\text{Root wt.}}$
		Canes in stool (gm.)	Roots (gm.)	0-12″	12-24″	24-36″	
Deep	10 days irrigation .	928·1	19·95	58·8	35·9	5·3	46·5
	20 days irrigation .	750·2	20·85	52·6	35·4	12·0	35·9

ROOT-SYSTEM OF WILTED AND CONTROL STOOLS
(SOIL TYPE 'B' DEEP, POJ 2878)

FIG. 1. Method of root study

FIG. 2. Wilted

FIG. 3. Control

ROOT STUDIES OF SUGARCANE
UNDER VARYING MANURIAL TREATMENTS
(POJ 2878)

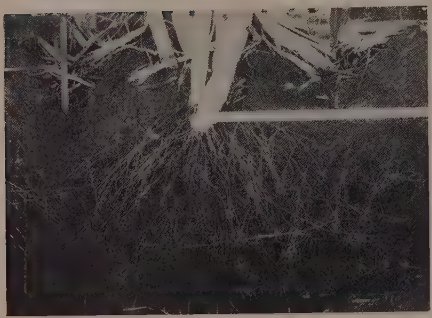

FIG. 1. No N

FIG. 2. 75 N

FIG. 3. 150 N

FIG. 4. 300 N

FIG. 5. 450 N

FIG. 6. 600 N

Although the total quantity of roots is practically similar in both the cases, it should be clear from their percentage distribution that in the case of 20 days irrigational turns, the root-system tends to be less superficial than in the normal treatment. The fall in the weight of stools, however, shows that in spite of this variation the crop has definitely suffered from the dearth of moisture as the soil nutrients were found to be on a higher level in this treatment than in the other. This can be ascribed to the failure of the root-system to penetrate deeper depths which were found on analysis to contain sufficiency of moisture throughout the period.

(c) *Nutrients*

In this tract, sugarcane is invariably manured, the most common manuring being the nitrogenous one consisting of sulphate of ammonia and oil-cakes. Soils are also found to be deficient in available phosphate, giving a good response to phsophatic manuring. During the course of the nutrition experiments with these elements, some studies in their influence on the root-system have also been carried out.

In the case of nitrogen, the treatments varied from no-nitrogen to 600 lb. of nitrogen, and the root-system is illustrated in Plate XVI for one of the two varieties under these treatments. The reduction in the root-system with increasing doses of nitrogen is quite visible. This has been further confirmed by the quantitative data for some of the treatments given in Table VIII which clearly indicate a progressive fall in the weights of roots with increasing doses of nitrogen.

TABLE VIII

Effect of varying doses of nitrogen on the root-system, November 1936

(Average of four stools)

Treatment	Oven-dry wt. of		Per cent distribution of roots			$\frac{\text{Stool wt.}}{\text{Root wt.}}$
	Canes in stool (gm.)	Roots (gm.)	0-12″	12-24″	24-36″	
POJ 2878—						
150 lb. N	480·0	29·1	49·4	50·6	..	16·5
225 lb. N	495·7	27·0	61·1	38·9	..	18·4
300 lb. N	645·6	24·0	62·0	38·0	..	26·9
450 lb. N	674·2	23·3	54·7	45·3	..	28·9
Pundia—						
150 lb. N	553·5	20·3	73·4	26·6	..	27·3
225 lb. N	506·6	17·6	74·2	25·8	..	28·8
300 lb. N	448·6	17·1	64·1	35·9	..	26·2
450 lb. N	663·5	15·3	58·0	42·0	..	43·4

The weights per stool on the other hand show in general an increase with increasing doses of nitrogen and there is thus an inverse relationship between the growth of the stem and the roots, which is explained by Turner [1922] as due to the increased use of carbohydrates in the tops owing to their combination with nitrogen. This results, according to him, in a decrease in the supply of carbohydrates for the roots, which may bring about an absolute or relative reduction of root growth. The figures for the distribution of roots in both the varieties reveal a tendency towards their increase in the lower depth in the case of higher nitrogen. Figures are available only for 2 ft. depths, as the soil under experimentation had that much depth only. In all these treatments also the irrigational dose was common and was kept very moderate in order to avoid leaching of nutrients. The increase in the roots in the lower depths in the case of higher manuring does not seem to be due to the phenomenon of leaching down of nutrients beyond the root zone as, in that case, the effect would have been the reverse, the intensity of root penetration being more in the case of lower manuring than in the higher one. It thus appears that this distribution of roots in the case of higher nitrogenous doses is only meant to support the high weight of the cane with a view to preventing its lodging.

The effect of phosphate on the root development has been studied in another experiment with different forms of phosphatic manuring, a nitrogenous dose of 300 lb. per acre being common to all. These results are given in Table IX.

TABLE IX

Effect of phosphatic manuring on root development, November 1937

POJ 2878..300 lb. N per acre

(Average of four stools)

Treatments*	Oven-dry wt. of		Percentage distribution of roots			$\frac{\text{Stool wt.}}{\text{Root wt.}}$
	Canes in stool (gm.)	Roots (gm.)	0-12″	12-24″	24-36″	
No P_2O_5 . . .	779·8	28·7	51·5	29·5	19·0	27·2
Superphosphate 100+0 lb. P_2O_5 . . .	994·3	29·5	49·1	31·9	19·0	33·7
Superphosphate 50 +50 lb. P_2O_5 . . .	1,304·6	35·7	41·4	41·5	17·1	36·6
Bone-meal 50+50 lb. P_2O_5 . . .	1,249·3	31·7	38·5	42·1	19·4	39·4
Nicifos 50+50 lb. P_2O_5	1038·5	27·5	48·3	29·2	22·5	37·7

* The first dose of manure was applied at planting and the second at the time of earthing.

It will be seen that except in the case of Nicifos, there is a favourable effect of phosphatic manuring on the root development. This is quite striking in the treatments of superphosphate and bone-meal, in which their quantities are applied in two doses, while superphosphate applied in one dose at planting time has not been so very effective. Weights of stools are also much higher in these treatments, this increase being more pronounced than in the roots. It would be thus seen that unlike nitrogen, phsophatic manuring is found to increase the weights of both the roots as well as the tops, their relation being thus direct. Among different phosphatic manures, superphosphate appears to be the best both for the root and shoot growth, while Nicifos is not quite effective. The latter has completely failed to produce a favourable effect on the root-system, while there is some increase in the cane weights over the no-phosphatic treatment. Comparative studies of the data from Tables VIII and IX would thus explain the reason why certain workers have been able to find positive correlation between the crop growth and root growth and others have not. As regards the distribution of roots, there does seem to be a definite tendency towards their greater development in the lower depths with phosphatic manuring, it being quite evident in both superphosphate and bone-meal applied in two doses.

(*d*) *Wind*

The Deccan Canal tract is very windy, especially during the months of April-September, the average wind velocity during this period often exceeding ten miles per hour. Plants on the windward side are, therefore, always found to be stunted in growth. In order to study the effect of exposure to wind on the root-system, a few stools both on the windward and leeward side of the same plot were examined, and the results are given in Table X.

TABLE X

Effect of wind on root development, October 1937

Co 413, 300 lb. N+100 lb. P_2O_5

(Average of two stools)

Treatments	Oven-dry wt. of		Per centage distribution of roots			$\frac{\text{Stool wt.}}{\text{Root wt.}}$
	Canes in stool (gm.)	Roots (gm.)	0-12″	12-24″	24-36″	
Exposd to wind .	409·1	37·2	58·3	34·0	7·7	11·0
Protected from wind .	486·8	25·4	37·4	31·6	31·5	19·2

Distinct variation in the root-system due to the exposure to wind is quite evident. Although the total quantity of roots is about 50 per cent higher than in the other case, the distribution o roots is quite superficial. This

increased weight of roots is found to be due to their greater thickness and it seems that the great energy, spent by the exposed plant in producing thick root-system in order to support the plant against wind, is the main reason for the poor performance of the aerial portion. The shoot/root ratio is therefore abnormally low. The adverse effect of wind is generally observed on the first two to three rows and it is found that it can be entirely avoided by providing suitable wind-breaks.

Root development and its relation to drought resistance

Varietal trials in progress at this station have shown the superiority of some of the varieties over the indigenous one—Pundia. In order to find out whether their superior growth could be related in some way to the root development, root-systems of some of the promising varieties grown under the same treatment of irrigation and manuring were exposed and quantitatively studied. The depth of the soil was about four feet. The data are given in Table XI.

Table XI

Root development of varieties, October 1937

300 lb. N+100 lb. P_2O_5

(Average of four stools)

Variety	Fresh wt. of canes in stool (gm.)	Oven-dry wt. of		Percentage distribution of roots			Stool wt./Root wt.
		Canes in stool (gm.)	Roots (gm.)	0-12″	12-24″	24-36″	
Pundia	2579	392	13·4	64·9	25·8	9·3	29·3
Co 426	3988	738	25·6	54·3	33·6	12·1	28·8
H M 89	2636	488	22·8	52·7	36·7	10·6	21·4
Co 413	2677	667	30·3	51·8	27·2	20·9	22·0
Co 421	2499	507	33·3	51·9	32·5	15·6	23·2
POJ 2878	3653	669	26·7	53·9	29·2	16·9	25·1
Co 360	2420	411	21·0	52·3	31·1	16·7	19·6
E K 28	2545	471	26·7	59·9	29·0	11·1	17·7

It will be noticed that there is a considerable variation in the development of roots among the varieties with practically no relationship of any kind between the root and shoot growth. Pundia has an extremely poor root-system, which is, at the same time, much shallower than in the others and still it has produced a stool of fairly good weight equal to many others, e.g. HM 89, Co 413, Co 360 and EK 28, having a much better root development. It is only due to high moisture content of cane that its dry weight shows a fall as compared to the above-mentioned varieties. On the other hand, Co 421 has given the highest weight of roots, without any corresponding effect on the stool weight. The capacity for root development thus seems to be independent of the plant growth. Evans [1937] has also come to a similar conclusion and explains it

as due to the fundamental difference in the shoot/root ratio in different varieties. From the inspection of the root-system of the varieties mentioned in Table XI, however, it seems that these varieties can be divided into two broad groups—one having thin and profusely branching root-system and the other possessing thick roots with comparatively less branching. The first group consists of varieties like Pundia, Co 360, EK 28, Co 426 and HM 89, while Co 421, POJ 2878 and Co 413 fall under the second group.

The data for distribution of roots clearly indicate that in all these promising varieties, more than 50 per cent of the roots are in the first foot depth of soil. Their maximum penetration has not also exceeded 3 ft., which is, as already explained, due to the deficiency of oxygen in the lower depths of this soil. There is practically very little variation among these improved varieties as regards the distribution of roots within different depths. This appears to be due to the controlled conditions of irrigation and manuring, and it has not been thus possible to draw any valid conclusions about the varietal characteristics from these studies alone. It was felt that this could be best achieved by the determination of their drought-resisting power. Besides anchorage, the main functions of roots would be the supply of water and nutriment to the various organs of plants, and the real criterion for judging the functional characteristics of the root-system should be its reaction to the deficiency of either of these. Irrigation was, therefore, stopped by about mid-April, when plants were about three months old and regular irrigations were begun only when each of the varieties showed a permanent wilting stage. The root-system was exposed after one more irrigation. An idea of the transpiring surface was also obtained by the product of the average length and breadth and the number of leaves. The data are given in Table XII.

TABLE XII

Relation of the root-system to the drought-resisting power of the varieties

Soil type—B medium

(Average of four stools)

Variety	Oven-dry wt of roots	Depth in.	Leaf area (sq. in.)	$\frac{\text{Leaf area}}{\text{Root wt}}$	No. of days required for wilting
Pundia	6·8	15·0	942·7	138·7	32
Co 426	8·7	19·0	999·7	114·9	38
HM 89	8·0	17·5	1164·2	145·5	39
EK 28	9·6	19·5	700·8	73·0	39
POJ 2878	9·8	27·0	937·0	95·7	48
Co 413	9·6	21·0	642·6	66·7	48
Co 360	12·0	26·0	656·8	54·7	54
Co 421	19·0	23·0	726·3	38·2	54

It will be evident that the influence of the root-system on the drought-resisting power of the varieties is circumscribed by their transpiring surface. In cases, however, where the transpiring surfaces are quite similar as in Pundia, Co 426 and POJ 2878 on the one hand, or Co 413, Co 421, EK 28

and Co 360 on the other, the period required for the attainment of permanent wilting is determined by the quantity of roots and their depth of penetration.

Summary and conclusions

Trials of several qualitative and quantitative methods devised by various workers for the study of the root-system of sugarcane have been found either to represent unnatural conditions or to be mostly very elaborate and time-consuming, leading to a great wastage of plant material. The writers have developed a quick method under the irrigated conditions of the Deccan, which enables one to study root-system *in situ* both qualitatively and quantitatively and the same has been described in detail. It has been further applied to the study of the effect of different environmental factors on the development of roots and the shoot/root ratios and the results are briefly summarized below :—

(1) Studies in the general development of the root-system have shown a gradient in the development of sett roots from the bottom to the top node in a three-budded sett, the largest quantity of roots being formed by the bottom node. With the production of shoot roots, these sett roots soon die. Before the operation of earthing, roots penetrate through the whole mass of soil in the ridge which contains much of the assimilable nitrogen. The most active period from the standpoint of the development of roots is the grand period of growth of the plant, when there is a profuse branching of roots with an increase in their depth penetration. This does not, however, exceed 36 in. in this soil inclusive of the earthed-up portion in spite of diverse treatments.

(2) The effect of the soil type is quite pronounced on the development of both roots and shoots. Even in the same soil type, there is a progressive fall in weights of roots with an increase in the depth of soil, which is traced to the deficiency of oxygen in lower depths. This deficiency appears to be accentuated in the *chopan* soil (alkali soil) in which the root-system is still restricted under quite similar treatments.

(3) Experiments with varying quantities of water show that higher watering tends to produce a superficial root-system and also create partially waterlogged conditions, adversely affecting the growth of roots and shoots in the case of Pundia and not in POJ 2878, thus bringing out varietal differences in this respect. The stoppage of water till permanent wilting when the plants were three months old has encouraged lateral spread of roots with very little increase in depth penetration. If, however, delayed waterings, such as irrigation at an interval of 20 days instead of the usual ten days, are continued throughout the life-cycle of the plant, the root-system tends to be less superficial than in the normal treatment although the total depth of penetration remains similar in both the cases.

(4) With the increase in nitrogenous manuring, there is a distinct reduction in the weight of roots and increase in that of shoots. On the other hand, phosphatic fertilizers produce a favourable effect on the development of both roots and shoots, their relation being thus direct. This is very striking in the case of superphosphate and bone-meal when applied in two doses, the first one at planting and the other at earthing-up time. Nicifos has been quite ineffective.

(5) Although plants on the windward side produce larger quantity of roots than those on the leeward side, these roots are thicker and quite superficial. The growth of the plants is, however, poorer and it seems the plants lose much of their energy in the formation of the root-system for anchorage against wind, resulting in their poor growth. This adverse effect of wind can be entirely avoided by providing suitable wind-breaks.

(6) Considerable variation is noticed in the development of roots of different varieties and no relationship of any kind can be established between the weights of their shoots and roots. A study of the drought-resisting power of the different varieties shows that it is mainly circumscribed by their transpiring surface, the quantity of roots and the depth of their penetration playing an important part in the case of varieties having equal transpiring surface.

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A STUDY OF FORECASTING OF COTTON CROP IN THE PUNJAB

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THE forecasting of yield of a crop before harvest is a subject of considerable economic importance in agriculture. In the Punjab the forecasts of cotton are based on the data supplied by the Agricultural and Revenue Departments. They involve two factors—acreage and yield. The former is accurate, while the latter is a personal estimate, and it is believed that the standard yield figures exercise a definite influence on the person responsible for forecasting the yield of the tract in his charge. Examination showed that the forecasts for several seasons were recurring underestimates ; consequently the revision of standard yield figures became necessary. An extensive statistical examination of all the crop-cutting experiments and other data for the period 1932-37 was undertaken, in order to evolve a suitable method for fixing the average yield of cotton for each district and each kind of cotton—*desi* and American, irrigated and unirrigated. The results of this investigation are briefly described in this paper.

Crop-cutting experiments

There are 28 districts in the Punjab where cotton is grown and out of these crop-cutting experiments are conducted in 23. Crop-cutting experiments are not, however, conducted for both *desi* and American cottons, and both kinds of cultivation, irrigated and unirrigated, in all the 23 disctricts, but in each district they are conducted for that kind of cotton which forms the major portion of the cotton crop in that district. The total area covered by these tracts in 1932-33 to 1936-37 was 12,087,405 acres out of 12,398,302 for the British districts of the Punjab, i.e. in about 97·5 per cent of the area the crop-cutting experiments were conducted. Hence if the crop-cutting experiments are sufficiently numerous, properly conducted and reported (and consequently are representative of the tracts in which they are made), the out-turn calculated from them will represent almost the whole of the cotton crop in the Punjab.

Average yield per acre based on crop-cutting experiments

In the five years 1932-33 to 1936-37, about 1,500 experiments were conducted, of which 600 were carried out by the Agricultural Department and 900 by the Revenue Department. Out of these 188 experiments were rejected for various reasons. As the number of experiments conducted by the Agricultural and the Revenue Departments each year was small, they were combined for the calculation of average yield for each district. The total number of experiments, together with the district yield figures calculated from them, are given in Tables I, II, and III respectively for *desi* irrigated, *desi* unirrigated, and American irrigated cottons.

TABLE I

Average yield of lint in lb. per acre for each district in different years
(*Desi* irrigated cotton)

District	1932-33		1933-34		1934-35		1935-36		1936-37		5 years (1932-37)		
	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Simple mean	Weighted mean
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Hissar	7	183	9	148	8	171	10	192	10	175	44	174	174
Rohtak	8	176	1	87	7	136	11	171	8	181	35	150	165*
Gurgaon	5	159	1	115	2	128	4	149	4	162	16	143	151*
Karnal	4	155	2	80	2	114	4	182	5	133	17	133	141*
Hoshiarpur	2	207	3	159	2	147	3	165	2	198	12	174	172
Jullundur	13	225	7	151	11	190	12	255	9	271	52	218	223*
Ludhiana	7	290	6	125	9	256	9	266	8	233	39	234	240*
Ferozepur	5	177	5	155	5	138	9	164	5	117	29	150	152
Lahore	11	132	9	123	13	138	8	136	19	142	60	133	135
Amritsar	7	164	5	115	3	139	5	152	5	185	25	151	153
Gurdaspur	2	158	3	122	3	135	1	175	3	174	12	153	149*
Sialkot	6	153	5	138	5	143	3	131	5	165	24	146	148
Gujranwala	6	178	4	153	5	127	5	141	4	136	24	147	149
Sheikhupura	6	116	4	163	6	144	9	162	9	151	34	147	148
Gujrat	2	122	1	122	3	136	1	97	4	157	11	127	136*
Shahpur	9	123	4	122	6	105	5	146	7	126	31	124	124
Montgomery	7	134	10	186	8	178	13	204	6	191	44	179	182
Lyallpur	3	123	17	207	14	155	22	174	30	175	86	167	176*
Jhang	4	137	4	108	1	155	3	129	5	133	17	132	129
Multan	7	129	11	137	13	119	13	114	18	115	62	123	121
Muzaffargarh	6	99	8	119	6	110	7	91	12	104	39	105	105
Dera Ghazi Khan	4	103	3	89	5	80	5	84	9	105	26	92	94

TABLE II

Average yield of lint in lb. per acre for each district for different years

(*Desi* unirrigated cotton)

District	1932-33		1933-34		1934-35		1935-36		1936-37		5 years (1932-37)		
	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Simple mean	Weighted mean
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Rohtak	2	83	1	58	3	82	2	106	6	76	14	81	81
Gurgaon	...	...	1	66	1	54	...	...	1	74	3	65	65
Karnal	1	91	1	41	1	89	2	91	3	77	8	78	79
Ambala	9	147	10	134	6	128	10	122	10	136	45	133	134
Hoshiarpur	6	128	2	142	5	157	4	117	5	147	22	138	138
Jullundur	1	93	1	78	1	103	1	111	...	...	4	96	96
Amritsar	1	68	2	77	2	72	2	85	1	84	8	77	78
Gurdaspur	4	87	4	105	4	74	4	128	2	92	18	97	98
Sialkot	2	67	1	82	2	58	2	99	2	91	9	79	79
Gujrat	...	...	3	73	2	90	1	87	2	87	8	84	83
Dera Ghazi Khan	...	...	...	...	2	74	1	87	3	75	6	79	77

Table III

Average yield of lint in lb. per acre for each district in different years

(American irrigated cotton)

District.	1932-33		1933-34		1934-35		1935-36		1936-37		(5 years 1932-37)		
	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Simple mean	Weighted mean
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Ferozepore	3	141	2	112	2	117	3	130	3	162	13	132	135
Lahore	5	160	5	150	7	179	2	165	21	153	40	161	159
Gujranwala	3	140	3	122	4	138	3	171	5	177	18	150	152
Sheikhupura	6	126	4	155	7	151	11	155	8	162	36	150	151
Gujrat	6	104	5	110	6	159	5	172	4	160	26	141	140
Shahpur	9	104	13	164	9	116	10	146	9	142	50	134	137*
Montgomery	7	150	10	213	9	174	13	204	8	205	47	189	192*
Lyallpur	6	132	17	163	33	146	30	178	40	161	126	156	160*
Jhang	7	111	7	138	7	129	10	155	10	137	41	134	136
Multan	5	103	11	155	14	119	20	123	11	130	61	126	128

Since there is a good deal of variation in the number of experiments conducted each year, the average yield for the five years is given as the weighted mean. For the sake of comparison, however, averages for each district obtained by the simple mean are entered in col. 13 and the places where there is noteworthy difference in average by the two methods are marked (*). The differences are fairly high for Rohtak, Gurgaon, Karnal and Lyallpur, for all of which the weighted mean is greater than the simple mean. Considering the mean yields of each year, we find that some are based on a very small number of experiments. Much reliance cannot be placed on such averages, and they can not truly represent the average yield of the season and the tract concerned. Thus for Rohtak and Gurgaon the figures 87 and 115, based on a single experiment each, are very low as compared with other seasons. In the case of *desi* unirrigated cotton, with the exception of Ambala, the number of experiments for each year for all the districts is very small. In fact, even the total number of accepted experiments for Gurgaon, Jullundur, Dera Ghazi Khan are from three to six—a number too small for obtaining a satisfactory mean value representing the average out-turn of a district. In view of all these facts, we cannot treat the district averages for each year separately, and the total out-turn for the five years has been obtained by multiplying the figures in col. 14 with the total area for five years for each district.

Reliability of district yields

In Tables IV, V and VI are given figures for the study of variability of yield of cotton of a given type in different districts. The standard deviation for each district is obtained from the individual yield figures of the five years after eliminating the effect of seasons by the analysis of variance (where possible). The figures in col. 5 of each of the three tables indicate the limits within which the results may vary owing to random causes, and they can be used as a rough guide for the rejection of doubtful experiments. If an experiment gives a yield lower or higher than the limits specified in this column, it should arouse suspicion, and the result should be rejected after scrutiny, unless there are very special reasons to retain it. In col. 7 is given the percentage error of the mean for the district average based on the number of experiments specified in col. 3. In col. 8 are the suggested numbers of experiments which should be conducted in future in each district if the percentage errors (col. 9) for the district averages thus obtained from such numbers are not to be exceeded. The figures in cols. 7 and 9 are calculated by using a formula $\frac{m^2e^2}{n}=x^2$ given in a previous investigation [Koshal and Turner, 1931] . In this formula, n is the number of experiments, x is the desired accuracy expressed as a percentage of the mean, and m is a factor fo obtaining particular odds. For odds of 19 : 1 ($P=0\cdot05$) m is $1\cdot96$, but as in the present cases, the standard deviations are calculated from the small number of experiments, m has been equated in each case to the value of t corresponding to the number of degrees of freedom on which the standard deviation given in col. 4 is based. Thus for Hissar, 33·4 is based on 39 degrees of freedom (after eliminating the effect of seasons) for which $t=2\cdot023$. Using this value we get the permissible limits of the experiments as 106—242 (the figures given in col. 5 are rounded to the nearest 5). The percentage error on either side of the mean is given by $\frac{19\times2\cdot023}{\sqrt{44}}=5\cdot8$. In order to obtain

higher accuracy, it is suggested that in future about 60 experiments (or 12 per year) should be conducted. The number of experiments suggested in col. 8 are only moderately higher than those conducted in the quinquennium 1932-37. It may be noted that the large number of experiments indicated in col. 3 for Lahore and Lyallpur is due to the inclusion of experiments conducted by the Settlement Officers at these places. Finally, in col. 10 areas under cotton in each district are expressed as a percentage of the total area under cotton cultivation in the Punjab. It will be noticed that the area for *desi* irrigated cotton is fairly large in Ferozepore, Lahore, Hissar, Montgomery and Lyallpur, while the major portion of the American cotton crop is grown in the districts of Montgomery, Multan, Lyallpur and Shahpur. It is essential to conduct a large number of experiments in these districts, so that a reliable average yield figure may be obtained from them. In fixing this number the variability of yield within a district should be taken into consideration. Thus in Lyallpur, in view of the lesser variablity (S. D.= 19 per cent) 60 experiments would be sufficient to ensure 5 per cent error in the district average, while for the same accuracy the number of experiments in Multan district (S. D.=25 per cent) should be 80. In Montgomery district, which is equally important, in view of the greater variability (S. D.= 27 per cent) the accuracy of the district yield based on 80 experiments is 6 per cent.

TABLE IV

Reliability of district yields

(*Desi* irrigated cotton)

District	District average lb. of lint per acre M	No. of experiments conducted in 5 years n	Standard deviation S. D. S	Permissible limits of experiments $P=\cdot05$ $M \pm St.$	Per cent S. D. e $e=\frac{S}{M}\times 100$	Percentage error of district average $P=0\cdot05$ x $x=\frac{e.t.}{\sqrt{n}}$	No. of experiments suggested n'	Percentage error of mean $P=\cdot05$ $x'=\frac{e.t.}{\sqrt{n'}}$	Percentage of area under cotton cultivation
1	2	3	4	5	6	7	8	9	10
Hissar . .	174	44	33·4	105-240	19	6	60	5	3·52
Rohtak . .	165	35	46·8	70-260	28	10	70	7	2·15
Gurgaon . .	151	16	26·7	95-205	18	9	25	8	0·52
Karnal .	141	17	31·8	75-210	23	12	40	8	1·99
Hoshiarpur .	172	12	33·1	100-245	19	12	20	9	0·10
Jullundur . .	223	52	51·5	120-320	23	6	50	6	1·21
Ludhiana . .	240	39	48·8	140-340	20	6	40	6	1·65
Ferozepore .	152	29	23·8	105-200	16	6	40	5	6·95
Lahore . .	135	60	34·2	70-200	25	6	60	6	6·39
Amritsar . .	153	25	27·8	95-210	18	8	50	5	3·15
Gurdaspur . .	149	12	27·4	90-210	18	11	25	8	0·69
Sialkot .	148	24	36·4	75-220	24	10	50	7	0·87
Gujranwala .	149	24	36·1	75-220	24	10	45	7	1·07
Sheikhupura .	148	34	27·7	95-200	19	6	40	6	1·67
Gujrat . .	136	11	29·9	70-200	22	15	30	9	0·47
Shahpur . .	124	31	40·8	40-210	33	12	60	9	2·24
Montgomery .	182	44	37·1	110-250	20	6	60	5	4·59
Lyallpur . .	176	86	32·1	110-240	18	4	50	5	6·63
Jhang . .	129	17	28·2	70-190	22	11	30	8	0·26
Multan . .	121	62	34·0	55-190	28	7	80	6	3·13
Muzaffargarh .	105	39	27·4	50-160	26	8	50	7	1·27
Dera Ghazi Khan.	94	26	24·9	45-145	26	11	40	9	0·70

TABLE V

Reliability of district yields

(*Desi* unirrigated cotton)

District	District average lb. per acre M	No. of experiments conducted in 5 years n	Standard deviation S. D. S	Permissible limits of experiments $P=0\cdot05$ $M \pm S.t.$	Per cent S. D. e $e=\frac{S}{M}\times 100$	Percentage accuracy of district average $P=0\cdot05$ $x=\frac{e.t}{\sqrt{n}}$	No. of experiments suggested n'	Percentage accuracy of mean $P=0\cdot05$ $x'=\frac{e.t}{\sqrt{n'}}$	Per cent area under cotton cultivation
1	2	3	4	5	6	7	8	9	10
Rohtak	81	14	23·2	30-130	28	16	30	11	0·44
Karnal	79	8	22·4	30-130	28	23	30	12	0·64
Ambala	134	45	39·1	55-210	29	9	60	8	1·71
Hoshiarpur	138	22	44·3	45-230	32	14	40	11	0·83
Gurdaspur	98	18	30·5	35-160	31	15	40	10	0·67
Sialkot	79	9	19·2	35-120	24	18	20	12	0·44
Gujrat	83	8	20·3	35-130	24	20	20	13	0·12

TABLE VI

Reliability of district yields

(American cotton)

District	District average lb. per acre M	No. of experiments conducted in 5 years n	Standard deviation S. D. S	Permissible limits of experiments $P=0\cdot05$ $M \pm S.t.$	Per cent S. D. e $e=\frac{S}{M}\times 100$	Percentage error of district average $P=0\cdot05$ $x=\frac{e.t}{\sqrt{n}}$	No. of experiments suggested n'	Percentage error of mean $P=0\cdot05$ $x'=\frac{e.t}{\sqrt{n'}}$	Per cent area under cotton cultivation
1	2	3	4	5	6	7	8	9	10
Ferozepore	135	13	37·5	55-215	28	18	30	11	0·41
Lahore	159	40	36·9	85-230	23	7	40	7	0·96
Gujranwala	152	18	41·1	65-235	27	16	30	11	0·91
Sheikhupura	151	36	27·5	95-205	18	6	40	6	2·61
Gujrat	140	26	23·7	90-190	17	8	30	6	1·96
Shahpur	137	50	41·0	55-220	30	9	70	7	5·16
Montgomery	192	47	51·7	90-290	27	8	80	6	9·43
Lyallpur	160	126	30·1	100-220	19	3	60	5	5·87
Jhang	138	41	28·4	80-195	21	7	70	5	3·57
Multan	128	61	32·7	65-190	25	6	80	5	9·46

Comparison of crop-cutting experiments with press returns

During the five years 1932-37, the total quantity of cotton pressed in different factories of the Punjab was 5,608,454 bales of 400 lb. The total area under cotton cultivation during the five years was 12,398,302 acres. Using this figure (and ginning percentage 32) we get an average out-turn of 6·87 md. of *kapas* baled from every acre of cotton grown in the Punjab. The average out-turn calculated from crop-cutting experiments is 5·75 mds. of *kapas* per acre or about one md. per acre less than the corresponding figure obtained from press returns. This shows that the district yield figures obtained from the crop-cutting experiments are underestimates and fall far short of the average production in the respective districts. There are several reasons for getting low yield from the crop-cutting experiments. In the first place they are not made in large numbers ; consequently they do not truly represent the average out-turn of the tract in which they are conducted. Secondly, cotton is picked several times at intervals and it is often difficult for a responsible officer to supervise each picking personally. Lastly, it is possible that part of the cotton is given as wages to the picker, thereby reducing the total weight obtained from a given area. It may also be noted that the actual crop produced in any one season may not be identical with the commercial crop of that season because : (*a*) a portion of the cotton grown in the adjoining Indian States may be imported into British territory for ginning and pressing, and *vice-versa*, (*b*) mixing up previous year's cotton crop with the new crop is practised to a certain extent. In order to make allowance for all the factors, the total out-turn calculated from the crop-cutting experiments is compared with that obtained from press returns for the five blocks separately. For the purpose of this study Ferozepore is combined with Jullundur to form one block.

TABLE VII

Approximate cotton crop of the Punjab calculated from crop-cutting experiments and press returns for the quinquennium 1932-37

(In bales of 400 lb. lint)

Block	Total area	Total area under crop-cutting tracts	Out-turn calculated from crop-cutting experiments		Out-turn obtained from press returns	Difference column 5 — column 6	
			For area in (3)	For area in (2)		Bales of 400 lb. lint	Per cent on col. (5)
1	2	3	4	5	6	7	8
Ambala . .	1,486,915	1,456,212	524,462	535,518	627,765	—92,247	—17
Jullundur . .	1,408,842	1,392,115	594,605	611,325	633,567	—22,242	—4
Lahore . .	2,488,774	2,422,025	860,493	884,200	943,396	—59,196	—7
Rawalpindi.	1,308,958	1,233,820	413,520	438,703	486,790	—48,087	—11
Multan . .	5,595,775	5,583,238	2,191,512	2,196,434	2,916,936	—720,502	—33
Total .	12,289,264	12,087,405	4,584,592	4,666,180	5,608,454	—942,274	—20

On comparison of the blocks it is found that the greater differences lie in Ambala and Multan blocks, and these are exactly the blocks which lie adjacent to Punjab States : Bahawalpur adjacent to Multan and Patiala, Jind, Nabha and Malerkotla adjacent to Ambala. Although it is known that some of the cotton produced in these states is being sent out to presses in Ambala division, the amount of cotton so imported cannot be specified on account of the inaccurate estimates made by these states. On the other hand, there is sufficient evidence to show that during the five years about two lakhs of bales were imported from Bahawalpur State to the presses situated in Multan division for ginning and pressing. We can, therefore, deduct 2 lakhs of bales from the total baled crop (for the five years) in Multan division, thereby reducing the discrepancy between crop-cutting experiments and press-returns from 33 per cent to about 24 per cent.

Home consumption of cotton

An estimate of the total production of cotton in a province is given by the following formula [I. C. C. C. Enquiry, 1936] :—

Approximate actual crop = (1) Cotton pressed + (2) loose (unpressed) cotton received at spinning mills + (3) net exports of loose cotton (all routes) + (4) village consumption of loose cotton, including *kapas*

Items (2) and (3) are usually very small as compared with (1) which has been dealt with in the last section. Consequently the other important factor is item (4) which relates to the quantity of cotton utilized for domestic purposes, such as hand-spinning, making quilts, mattresses, etc. In order to estimate it, an enquiry was made by the Indian Central Cotton Committee [1936] in all the provinces of India. As a result of this enquiry, the following average figures for home consumption were obtained for the Punjab.

	Per capita consumption in lb. of lint
A. *Desi* cotton	
1. Major cotton-growing tract	3.70
2. Minor cotton-growing tract	2.98
3. Non-cotton growing tract	2.35
B. American cotton	0.135

These figures were used in calculating the total quantity of cotton consumed for domestic purposes. The census of 1931 showed [Dept. Agric. Punjab Rep., 1937] that the population during the preceding ten years had increased by an average of 1·1 per cent annually. Assuming this increase to have continued, home consumption of cotton for the five divisions was calculated, and the results are given in col. 3 of Table VIII. In order to get the total production of cotton in each division (col. 4) these figures are added to the outturn obtained from press returns.

Table VIII

Comparison of total out-turn (press returns+home consumption) with estimates obtained by crop-cutting experiments, 1932-37

(In bales of 400 lb. lint)

Division	Actual out-turn obtained from press returns	Calculated home consumption	Total	Out-turn calculated from crop-cutting expts.	Difference col. 5 & 4: Bales	Difference col. 5 & 4: Per cent on average of cols. 4 & 5
1	2	3	4	5	6	7
Ambala . .	615,210	144,192	771,957	535,518	—236,439	—36
Jullundur . .	620,896	160,884	794,451	611,325	—183,126	—26
Lahore . .	924,528	263,580	1,206,976	884,200	—322,776	—31
Rawalpindi. .	477,054	87,277	574,067	438,703	—135,364	—27
Multan . .	2,658,597	242,975	2,959,911	2,196,434	—763,477	—30
Total .	5,296,285	898,908	6,507,362	4,666,180	—1,841,182	..

Revised standard yield figures of cotton

To allow for home consumption and difference as shown by press returns, the district yields obtained from crop-cutting experiments in each division have to be increased by the percentage figures given in col. 7 of Table VIII. Analysis of covariance was applied to the revised figures of production thus obtained, and the corresponding figures calculated from the results of crop-cutting experiments, and in this manner the following three equations have been deduced :—

(1) $Y=1\cdot249X+15\cdot14$ for Ambala block

(2) $Y=1\cdot249X+5\cdot86$ for Jullundur -Lahore block

(3) $Y=1\cdot249X+6\cdot08$ for Shahpur-Multan block,

where X is the average district yield calculated from crop-cutting experiments, $1\cdot249$ is the 'average regression within blocks', and Y is the probable district yield in lb. of lint per acre. The figures (rounded to nearest 5) of average yield in lb. per acre calculated from these equations are presented in Table IX, and these may be regarded as the new quinquennial standard yield figures of

cotton for the 23 districts and for the kind of cotton and type of irrigation to which they refer. There still remain five districts and the tracts in 23 districts, where crop-cutting experiments have not been conducted. It may be recalled that these cover only about $2 \cdot 5$ per cent of the total area under cotton cultivation in the British districts of the Punjab. However, the standard yields for these are also included in Table IX, and they have been fixed by comparing the total out-turn obtained from the new standard yields in each of the five divisions with the out-turn calculated from the corresponding figures of the last quinquennium. Thus, if the difference for one division is X per cent, then the standard yield figures of the last quinquennium for the districts and tracts where no crop-cutting experiments have been conducted may be raised by X per cent in order to get the revised standard yield figures for the period 1932-37, for that division.

TABLE IX

*Standard yield * figures of cotton in lb. of lint per acre, in each district of the Punjab for the period 1932-37*

District	*Desi*		American	
	Irrigated	Unirrigated	Irrigated	Unirrigated
1. Hissar	230 (150)	120 (90)	..	..
2. Rohtak	225 (160)	110 (70)	..	..
3. Gurgaon. . . .	210 (140)	90 (70)	..	..
4. Karnal	195 (150)	110 (80)	..	..
5. Ambala	200 (150)	185 (130)	..	..
6. Simla	..	..	..	..
7. Kangra	95 (64)	75 (50)	..	..
8. Hoshiarpur . . .	220 (180)	180 (130)	..	..
9. Jullundur . . .	285 (180)	120 (110)	..	..
10. Ludhiana . . .	305 (190)	120 (82)	..	..
11. Ferozepore . . .	195 (110)	90 (60)	175 (115)	120 (80)
12. Lahore . . .	175 (110)	95 (70)	205 (150)	100 (72)
13. Amritsar . . .	200 (150)	100 (90)	..	..
14. Gurdaspur . . .	195 (160)	125 (120)	..	..
15. Sialkot	190 (140)	100 (100)	..	..

TABLE IX—*concld.*

District	*Desi*		American	
	Irrigated	Unirrigated	Irrigated	Unirrigated
16. Gujranwala	190 (110)	95 (70)	195 (170)	125 (90)
17. Sheikhpura	190 (100)	110 (80)	195 (170)	110 (80)
18. Gujrat	180 (110)	105 (80)	180 (120)	125 (90)
19. Shahpur . . .	160 (110)	50 (35)	175 (120)	100 (74)
20. Jhelum	200 (146)	85(61)	..	..
21. Rawalpindi . . .	160 (116)	140 (100)	..	..
22. Attock	150 (110)	70 (50)	..	..
23. Mianwali . . .	110 (80)	70 (50)	..	..
24. Montgomery . . .	235 (120)	105 (70)	245 (140)	120 (80)
25. Lyallpur . . .	225 (140)	..	205 (150)	..
26. Jhang	165 (100)	90 (60)	175 (110)	..
27. Multan	155 (90)	90 (62)	165 (105)	110 (75)
28. Muzaffargarh . . .	135 (90)	75 (50)	..	..
29. Dera Ghazi Khan . .	125 (80)	100 (60)	..	..
Provincial average . .	203 (126)	128 (97)	196 (130)	113 (72)
" "	193 (123)		195 (130)	

* The figures in brackets are the last quinquennial standard yields.

The new standard yield figures given in Table IX may be regarded as approximately representing the average production (in lb. of lint per acre) in each district and for each type of cotton. They are considerably higher than the old ones, with the result that the provincial standard yields for *desi* and American cottons are raised from 123 and 130 lb. to 193 and 195 lb. respectively. As the revised district yields will be a guide for future forecasts, it is hoped that the dangers of under-estimation will be reduced.

Suggestions for conducting the crop-cutting experiments in order to ensure more satisfactory results

Since crop-cutting experiments are designed to check the average yield of a district, they must conform to the following two conditions :—

(1) A large number of experiments should be carried out in each district so that every type of soil and climate may be well represented. (2) Each experiment should be conducted in such a manner as to be representative of the tract in which it is conducted.

A number of fields should be selected in an average village in the assessment circle concerned, and from them at least two fields may be taken at random for crop-cutting experiments. Each field may be divided into two parts, and from each part two sampling units may be taken at random, and the produce from each weighed separately. This procedure will ensure adequately both randomization and representativeness. The question of the best size of the sampling unit may be settled by conducting a preliminary experiment (involving different sizes of sampling units) in one district.

Experiments on these lines should first be conducted in five districts—one district selected from each of the five divisions. In addition to the yield, some measurable characters, such as number of plants and of bolls on the plant, height of the main axis, etc. of the growing crop should be recorded. If this is done for a number of years, it would probably be possible to find out definite measurements which are closely related to the yield, and these can subsequently be used for forecasting purposes. Thus for the wheat crop, Yates [1936] has shown that plant number and shoot height are significantly associated with the final yield.

Acknowledgement

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ENTOMOLOGICAL INVESTIGATIONS ON THE LEAF-CURL DISEASE OF TOBACCO IN NORTHERN INDIA

IV. TRANSMISSION OF THE DISEASE BY WHITE-FLY (*BEMISIA GOSSYPIPERDA*) FROM SOME NEW ALTERNATE HOSTS

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(With Plates XVII and XVIII and two text-figures)

Introduction

Our investigations on the leaf-curl disease of tobacco started in 1935 [Pruthi and Samuel, 1937, 1939] were continued at Pusa (Bihar) during the seasons 1938-39 and 1939-40 on a much more extensive scale than in the previous years, with the object of determining alternate host plants of the leaf-curl virus or viruses and the possibility of transmitting the disease from them to healthy tobacco by the white-fly, *Bemisia gossypiperda* M. and L. Several series of experiments have been performed and they confirm our previous conclusions about the transmission of the disease from sunn-hemp and *Ageratum conyzoides* to tobacco, and *vice versa*. Several additional weeds and cultivated plants have been observed in the environs of Pusa suffering from leaf-curl, reminiscent of the disease in tobacco. Of such numerous new plants investigated, several seem to be important hosts and the results of investigations thereon are reported in this paper.

Some transmission experiments with another species of *Bemisia*, viz. *Bemisia giffardi* Kot., collected from *Jasminum sambac*, were also performed to ascertain whether any other species of *Bemisia*, besides *B. gossypiperda*, could also transmit the disease to healthy tobacco. The results of this investigation are also summarized in the following pages.

Technique, material, etc.

The technique adopted in our previous investigations for encasing the white-fly on the food plants for ensuring its feeding thereon has been slightly modified. In the micro-cage described previously [Pruthi and Samuel, 1939], instead of using a tube open at one end, a tube open at both ends was employed (Fig. 1). The mouth of the tube away from the leaf-surface was covered with a wire-gauze thimble (a) which permitted free aeration inside the tube and thus the encased white flies lived much longer, and remained more active than in the old form of the cage.

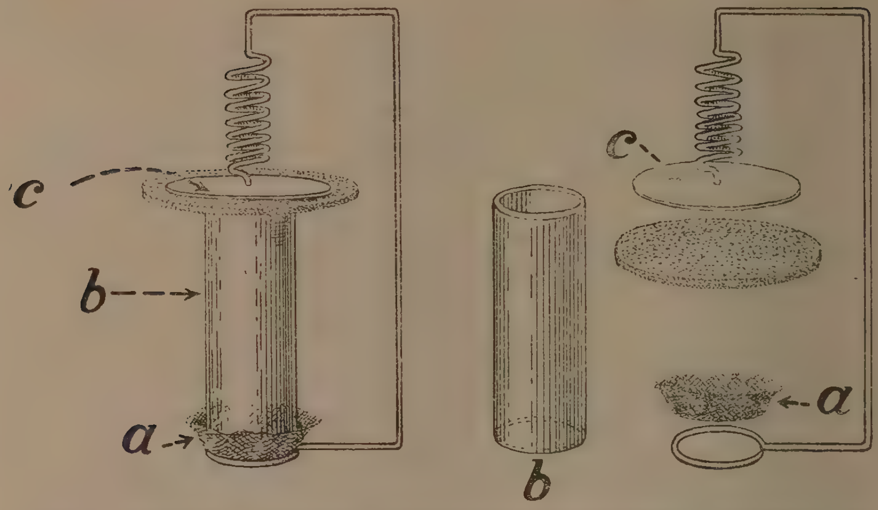


FIG. 1. Micro-cage for feeding white-flies for the transmission experiment. On the right the various parts of the cage are shown separately. [**a**. wire-gauze thimble; **b**. glass tube with both ends open; **c**. spring with disc]

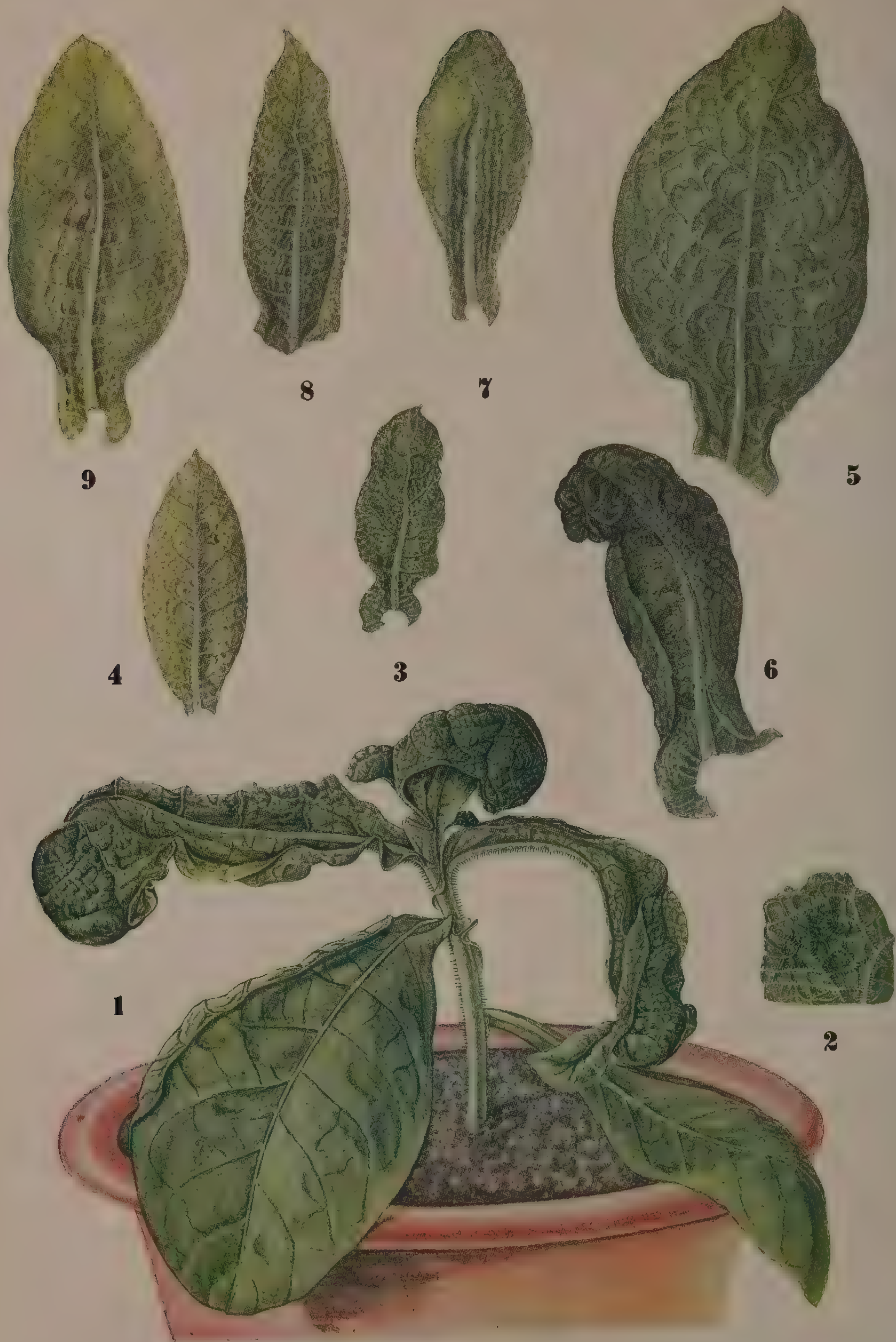
As in previous years, tobacco seedlings (I P hybrid 142) for experimental purposes were raised under strict insect-proof conditions and transplanted in pots containing sterilized soil and were kept covered with muslin bags throughout their life. In order to have seedlings of different ages always available for experiments, tobacco was sown every month for eight months from June to January. Though tobacco is normally harvested at Pusa from the end of January onwards, the inoculated plants under our experiments were kept under observation for noting the appearance of the disease up to the middle of April, when it grew too hot for keeping the plants in the field. The plants continued to give out side-shoots up to about the middle of March.

TRANSMISSION OF THE DISEASE FROM *ZINNIA ELEGANS*

Garden zinnias (*Zinnia elegans*) were noticed during August to October to be suffering from a leaf-curl disease, resembling to some extent the disease in tobacco. *B. gossypiperda* was also observed feeding and breeding on them. It was, therefore, suspected that this plant might prove to be the alternate host of the tobacco leaf-curl virus. In order to test this view, and also to determine whether the white-fly could transmit the disease from zinnia to tobacco four series of experiments were performed during September to January in1938-39 season, and eight series in 1939-40, the particulars and result of which are summarized in Table I.

In 1938-39, the percentage of successful transmission varied from 47 to 87, the maximum being in the case of series ii. In this series, 13 out of 15 plants, which were about eight weeks old and had been inoculated on 8 November, developed leaf-curl in 18-39 days.

The minimum number of white-flies and the minimum period of their feeding, tested for successful transmission, were one specimen (series iii) and one hour (series ii) respectively



1. A tobacco plant in which disease was produced by experiment, using diseased zinnia as source of infection. **2.** A portion of leaf of the above plant magnified. **3.** A leaf of a similarly diseased plant. **4.** A leaf of a tobacco plant in which disease was produced by experiment, using diseased *Euphorbia hirta* as source of infection. **5** and **6.** A leaf of a tobacco plant in which disease was produced by experiment, using diseased *Vernonia cinerea* as source of infection. **7.** A leaf of a tobacco plant in which disease was produced by experiment, using diseased *Sida rhombifolia* as source of infection. **8** and **9.** A leaf of a tobacco plant in which disease was produced by experiment, using

TABLE I

*Particulars of experiments performed to transmit the disease from zinnia to tobacco**

Serial No.	Time of experiment	Age of tobacco infected (weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
						1938-39				
(*i*)	10-11 Sept. 1938	8½	4	12—18	17	3	$\frac{12}{17}$	38	75	3, *A*
(*ii*)	8 Nov. 1938	8	15	3—9	1—7	13	$\frac{3}{1}$	18—37	87	6, *DX*; 2, *C*; 3, *B*
(*iii*)	7-8 Dec. 1938	8	15	1—20	16	7	$\frac{1}{16}$	22—35	47	2, *D*; 2, *DX*; 3, *X*
(*iv*)	5-7 Jan. 1939	8	6	3—24	8—16	5	$\frac{3}{8}$	27—38	83	2, *DX*; 3, *BX*
						1939-40				
(*i*)	4 Aug. 1939	11	11	2—16	1	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*ii*)	2 Sept. 1939	11	8	3—8	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	14-15 Sept. 1939	9	10	2—6	22	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iv*)	24-25 Oct. 1939	10	19	1—15	4½—24	4	$\frac{1}{4\frac{1}{2}}$	25—72	21	4, *X*
(*v*)	11-12 Nov. 1939	8	13	1—12	7—21	6	$\frac{3}{7}$	26—30	46	2, *C*; 3, *C* & *D*; 1, *A* & *D*
(*vi*)	4-5 Dec. 1939	7	22	4—16	6½—22½	1	$\frac{8}{22\frac{1}{2}}$	29	5	1, *C*?
(*vii*)	7 Dec. 1939	8	6	5—11	5½	1	$\frac{9}{5\frac{1}{2}}$	30	17	1, *C*
(*viii*)	27 Dec. 1939	[illegible]	10	4—15	[illegible]	2	$\frac{10}{6}$	37	20	Type not formed

* None of the controls of the various series developed leaf-curl disease

The most common type of leaf-curl produced in tobacco was *D*, often mixed with *X*, but sometimes *A*, *B* and *C* types were also produced. A typical tobacco plant and leaves of some other plants in which disease was thus produced by experiment are shown in Plate XVII, figs. 1-3.

Transmission experiments with zinnia as the source were repeated during the 1939-40 season, when no less than 99 infections under eight series were carried out from August to December (Table I). The highest percentage of successful transmission was, however, 46 only (series v). The common types of disease produced were *B*, *C*, *D* and *X*.

From the foregoing, it is evident that *Zinnia elegans* is an important alternate host of the tobacco leaf-curl disease, especially of *B*, *C*, *D* and *X* types, and that the white-fly can transmit the disease easily from this host to healthy tobacco.

Zinnias are planted in gardens in north Bihar in the month of June soon after the early rains. Leaf-curl generally appears in them from August to October and persists up to January. Tobacco is planted in the field during the last week of September or early in October. Therefore in nature, diseased zinnias seem to act as an important source of infection for the tobacco crop.

Transmission of the disease back to zinnia from tobacco and some other plants

In order to determine whether the leaf-curl disease could be transmitted back to *Zinnia elegans* from tobacco, eight transmission experiments, the results of which are summarized in Table I-A, series i, were performed on 4-5, August, 1939 on four-weeks old healthy zinnia seedlings. Diseased tobacco plants of the previous season which had developed *DX* type were utilized for inoculation purposes. One to five white-flies which had been allowed to feed on the source for 18 hours were introduced on each zinnia plant. After 11-29 days, seven out of eight inoculated plants developed typical leaf-curl (Plate XVIII, figs. 1-4).

Since some weeds, viz. *Vernonia*, *Scoparia*, *Euphorbia*, etc. were frequently noticed near the zinnia plants at Pusa, exhibiting symptoms of some leaf-curl disease, it was suspected that the disease could perhaps be transmitted to zinnias from these weeds also by means of the white-fly. To test this hypothesis, about 26 inoculations, the details of which are given in Table I-A, series ii-iv, were performed in August on healthy zinnia seedlings about four weeks old, using the diseased weeds, named above, as sources. In the case of *Vernonia* to *Zinnia*, all the 12 seedlings inoculated developed severe leaf-curl symptoms. In the case of *Scoparia* to *Zinnia* and *Euphorbia* to *Zinnia*, five out of seven inoculated plants became diseased. The structure of the leaves of zinnia plants in which disease was produced by experiment with the weeds mentioned above as sources of infection are shown in Plates XVIII, figs. 5-7.

Mathur [1933] has shown that *B. gossypiperda* can transmit leaf-curl from diseased to healthy zinnias. To confirm this, 14 healthy seedlings were inoculated each with 1-10 white-flies after they had been allowed to feed on diseased zinnia for 18 hours. All the plants so inoculated developed severe symptoms of leaf-curl in 11-29 days. It is not presumed that the virus at Pusa is the same as at Dehra Dun.

PLATE XVIII

1. A plant of *Zinnia elegans* in which disease was produced by experiment, using diseased tobacco as source of infection. **2** and **3.** Leaves of the same, magnified. **4.** Leaf of another zinnia plant similarly diseased. **5** to **7.** Leaves of zinnia plants in which disease was produced, using diseased *Euphorbia*, *Scoparia* and *Vernonia* as source of infection, respectively. **8.** Leaf of a healthy zinnia plant.

TABLE I-A

Particulars of experiments performed to transmit the disease to Zinnia elegans *from various plants (1939-40)**

Serial No.	Time of experiment and type of source of inoculation	Age of zinnia infected (weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
				Tobacco to zinnia						
(*i*)	4-5 Aug. 1939 (*DX*) .	4	8	1—5	18	7	$\frac{1}{18}$	11—29	87	Type is like that which occurs in nature
				Vernonia cinerea to zinni						
(*ii*)	7-8 Aug. 1939 . .	4	12	5—7	14	12	$\frac{5}{14}$	21—23	100	Do.
				Scoparia dulcis to zinnia						
(*iii*)	6-7 Aug. 1939 .	4	7	1—5	22	5	$\frac{1}{22}$	15—34	71	Do.
				Euphorbia hirta to zinnia						
(*iv*)	6-7 Aug. 1939 .	4	7	2—5	20	5	$\frac{2}{20}$	27	71	Do.
				Zinnia to zinnia						
(*v*)	4-5 Aug. 1939 . .	4	14	1—10	18	14	$\frac{1}{18}$	11—29	100	Do.

* None of the controls of the various series developed leaf-curl disease

From the foregoing it is evident that zinnia could act not only as an alternate host of tobacco virus, but could also receive infection of the disease back from tobacco. Furthermore, zinnia itself has three other important alternate hosts of the virus, viz. *Vernonia*, *Scoparia* and *Euphorbia*, from which it gets infected, besides itself acting as an independent source of infection to healthy zinnia in the field.

Transmission of the disease from *Solanum nigrum* to tobacco

Solanum nigrum is also an important food plant of the white-fly at Pusa, and it shows symptoms of a leaf-curl disease. It is a very common weed in North Bihar, particularly near tobacco fields. Transmission experiments were performed to determine whether this plant was also an alternate host of tobacco leaf-curl virus. During 1938-39, four series of experiments were performed in which 55 tobacco seedlings were inoculated, using diseased plants of *Solanum nigrum* collected from the field as source of infection. The work was repeated in 1939-40 and 15 transmission experiments were performed. The results of experiments are given in Table II.

An examination of Table II will show that in 1938-39, the percentage of successful transmission was some times very high, 94-100 per cent (series i and ii). The experiments in these series were performed during July and August. In 1939-40, when all the experiments were done in December and January, the percentage did not go higher than 20-30.

Thus *S. nigrum* is another important alternate host of the tobacco leaf-curl virus of *B*, *C*, *D* and *X* types. It may be stated, however, that the incidence of the disease in *S. nigrum* at Pusa is generally very low, but the few plants which suffer from leaf-curl do so very severely. Such plants can be easily destroyed from the neighbourhood of tobacco crops.

Transmission of the disease from *Euphorbia hirta*

Euphorbia hirta is also one of the common weeds in North Bihar. It also suffers from a leaf-curl disease and is a host of the white-fly. Between July and October 1938, five series of transmission experiments with diseased plants of this weed collected from the field as the source of inoculations were performed on 6-10 weeks old tobacco seedlings. Similarly six series of experiments involving 58 inoculations were performed in 1939. The results of the two years' work are summarized in Table III. An examination of the table will show that the maximum percentage of infection was 67 in 1938-39 (series i) and 70 in 1939-40 (series iv). The experiments under these series were performed in July and October respectively.

The general type of disease developed was *B* and *C* in combination with *X* (Plate XVII, fig. 4). The minimum number of white-flies tested which transmitted leaf-curl was one, and the minimum feeding period tested for successful transmission was six hours. The incubation period of the disease varied from 11 to 64 days.

Transmission of the disease from *Vernonia cinerea*

Vernonia cinerea is a common weed in the neighbourhood of Pusa and serves as a food plant for thewhite-fly. It occasionally suffers from leaf-curl the disease. In 1938-39, 84 transmission experiments under six series, and in

TABLE II

Particulars of experiments performed to transmit the disease from Solanum nigrum *to tobacco**

Serial No.	Time of experiment	Age of tobacco infected (Weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
					1938-39					
(*i*)	22-26 July 1938	10	17	1—15	8—24	16	$\frac{1}{8}$	11—28	94	1, *BX*; 7, *C* & *D*; 8, *DX*. One plant of *DX* recovered; 3 plants had large leaf-like enations.
(*ii*)	4-5 Aug. 1938	7	1	3	24	1	$\frac{3}{24}$	20	100	1, *CX*
(*iii*)	11 Oct. 1938	8	12	2—12	8	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iv*)	9 Nov. 1938	8	15	1—8	9	1	$\frac{1}{9}$	25	7	1, *X*
					1939-40					
(*i*)	8-9 Dec. 1939	8	5	7—11	$4\frac{1}{2}$—$22\frac{1}{2}$	1	$\frac{11}{4\frac{1}{2}}$	48	20	*Nil*
(*ii*)	5 Jan. 1940	$7\frac{1}{2}$	10	5—17	$17\frac{1}{2}$	3	$\frac{7}{17\frac{1}{2}}$	27—43	30	*Nil*

*None of the controls developed leaf-curl disease.

1939-40, 68 inoculations under six series were performed with a view to ascertaining if this weed was also an alternate host of tobacco leaf-curl, and whether the white-fly could be the vector concerned. Diseased plants this weed were collected from the field for inoculation purposes. The results of the experiments are summarized in Table IV.

In 1938-39, the highest positive transmission obtained was 27 per cent (series vi). In this series, 15 inoculations were done on eight weeks old tobacco seedlings on 7-8 February. After 23-25 days, four plants, on which 10-15 specimens of white-flies had been introduced, developed leaf-curl symptoms, but two of them ultimately recovered. In 1939-40, the highest percentage of positive transmission obtained was 70 (series iv). In this series, 10 tobacco seedlings, about nine weeks old, were inoculated in October each with 8-20 white-flies after a feeding period of six hours on the diseased source. Seven seedlings developed leaf-curl in 14-41 days. The lowest positive transmission was 10 per cent (series vi). In three series, viz. Nos. (ii), (iii) and (v), no positive results were obtained.

From the foregoing it will be seen that the disease can be transmitted from *V. cinerea* to tobacco by the white-fly, though the percentage of positive transmission is not so high as in the other alternate hosts described in the preceding pages. It may be mentioned that Thung [1934] was also able to transmit leaf-curl from *Vernonia cinerea* to healthy tobacco in Java and obtained a high percentage of positive results. From the examination of results given in Table IV, it is evident that majority of the inoculated seedlings developed *C* and *A* types of leaf-curl, which were sometimes mixed with *X* and *D* types (Plate XVII, figs. 5 and 6). The minimum number of white-flies which successfully transmitted the disease was one, and the minimum feeding period tested for the transmission was six hours.

Diseased plants of *Vernonia* are not of common occurrence at Pusa, but the small number of plants which are infected show symptoms of virulent type of leaf-curl.

Transmission from tomato, *Lycopersicum esculentum*

Tomato in North Bihar frequently suffers from a serious type of leaf-curl resembling bunchy-top of tomato virus 2 [Johnson, 1927] in U. S. A., described by McClean [1931]. Since it is also a favourite food plant of the white-fly, three series consisting of 51 inoculations and the same number of series consisting of 30 inoculations were performed with this plant during 1938-39 and 1939-40 respectively. The results are summarized in Table V. In 1938-39, the percentage of successful transmissions varied from 4 (series iii) to 56 (series ii). In the latter series, 16 tobacco plants, eight weeks old, were inoculated on 10-11 February by means of six to ten white-flies after they had fed for 24 hours on diseased tomato. Nine plants developed leaf-curl, of which five showed *A* type, and two *X* type. Two other plants which showed traces of *X* type, subsequently recovered before the end of the season. The incubation period of the disease was 20-27 days. The minimum number of white-flies tested which transmitted the disease was seven. In 1939-40, the highest percentage of positive transmission was 20

TABLE III

Particulars of experiments performed to transmit the disease from Euphorbia hirta *to tobacco**

Serial No.	Time of experiment	Age of tobacco infected (weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
					1938-39					
(*i*)	25 July 1938	10	9	2—12	6	6	$\frac{2}{6}$	11—27	67	Plants died before type formation
(*ii*)	25-26 July 1938	6	9	1—15	23	2	$\frac{1}{23}$	10—36	22	1, *CX* ; 1, *C*. *C* recovered
(*iii*)	23 Aug. 1938	10	10	4—20	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iv*)	1-3 Sept. 1938	7	12	1—11	24	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*v*)	6-7 Oct. 1938	8	10	5—20	22	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
					1939-40					
(*i*)	27-28 July 1939	10½	7	2—8	14	2	$\frac{5}{14}$	14—25	29	2, *X*
(*ii*)	1 Sept. 1939	11	11	2—11	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	13 Sept. 1939	8½	10	3—6	7½	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iv*)	17 Oct. 1939	9	10	6—16	6	7	$\frac{10}{6}$	14—64	70	6, *BX* ; 1, *X*
(*v*)	10-11 Nov. 1939	8	10	7—16	7—11	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*vi*)	29 Dec. 1939	6½	10	7—14	6	1	$\frac{11}{6}$	4	10	Type not formed

* None of the controls in the various series developed leaf-curl disease.

TABLE IV

Particulars of experiments performed to transmit the disease from Vernonia cinerea *to tobacco**

Serial No.	Time of experiment	Age of tobacco infected (weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
					1938-39					
(*i*)	5-7 Sept. 1938	8	12	1—18	38	2	$\frac{1}{38}$	17—23	17	2, *X*; large enations present
(*ii*)	10-11 Oct. 1938	8	12	3—12	24	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	6-7 Nov. 1938	8	15	1—25	1—17	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iv*)	11-14 Dec. 1938	9	15	4—15	24	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*v*)	2-3 Jan. 1939	7½	15	3—20	24	1	$\frac{10}{24}$	50	7	Recovered
(*vi*)	7-8 Feb. 1939	8	15	8—40	24	4	$\frac{10}{24}$	23—25	27	2, *X*; 2 other plants recovered
					1939-40					
(*i*)	27-28 July 1939	10	7	1—12	14	1	$\frac{6}{14}$	14	14	*X*
(*ii*)	30-31 Aug. 1939	11	10	2—8	6	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	12 Sept. 1939	8½	10	3—8	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iv*)	17 Oct. 1939	9	10	8—20	6	7	$\frac{9}{6}$	14—41	70	4, *CX*; 1, *A* & *C*; 2, *A* & *D*
(*v*)	10 Nov. 1939	10	10	6—16	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*vi*)	5-29 Dec. 1939	7—7½	21	6—13	6—7	2	$\frac{12}{7}$	25—35	10	1, A

* None of the controls of the various series developed leaf-curl disease.

(series i) when 10 tobacco seedlings, about nine weeks old, were inoculated on 16-17 November each with 5-14 white flies, which had fed on the diseased source for 21 hours. The incubation period of the disease was 22-29 days.

Transmission of the disease from *Launea asplenifolia*

Launea is one of the most common perennial weeds in tobacco fields in North Bihar. It seems to have two great flushes in the year, i.e. one during February to April and another during July to September. Leaf-curl appears in this weed chiefly in the colder months, viz. November to February. Three series of transmission experiments in 1938-39 and six series in 1939-40 were performed with this host plant, the results of which are summarized in Table VI. In 1938-39, the highest percentage of positive transmission was 50 (series iii) when 10 inoculations on nine weeks old tobacco plants were done on 12-13 February. Twelve to twenty-three white-flies which had been allowed to feed on diseased weed for 24 hours before were transferred to healthy tobacco seedlings. Five plants developed leaf-curl in 20-25 days. The minimum number of white-flies tested for the transmission of the disease was five. In 1939-40, the maximum percentage was 44 (series v), when nine tobacco plants, eight weeks old, were inoculated on 7 December. Four plants showed positive reaction, but the exact type of the disease could not be distinguished. The incubation period of the disease was 35-57 days. The minimum number of white-flies and their minimum feeding period tested for successful transmission of the disease was 2 and 5½ hours respectively.

Transmission of the disease from *Sida rhombifolia*

Sida rhombifolia is also a common weed (annual) in North Bihar, which grows profusely on the field bunds, river banks and road sides. The season of its growth begins in the rainy months of July-August and lasts up to the end of February after which it practically dies out. Disease generally appears in this weed during autumn. For inoculation purposes, diseased plants were collected from the field, and six series of experiments in 1938-39 and eight series in 1939-40 were performed, the results of which are summarized in Table VII.

In 1938-39, the highest percentage of successful transmission was 39 (series i), when 23 tobacco plants, seven to eight weeks old, were inoculated by introducing per plant 3-31 white flies which had fed for 12-15 hours on the diseased weed. Nine plants on which six specimens had been put showed reaction. Three of these developed *A* type, one *AX* and one *C*, while the remaining four practically recovered by the end of the season. The minimum number of white-flies tested for the transmission of the disease was three. The incubation period of the disease was 19-45 days. In 1939-40, the maximum positive transmission was 20 per cent (series iv), when 21 tobacco plants, about ten weeks old, were inoculated on 26-30 October each with 1-32 white-flies which had fed for 17-24 hours on diseased source. The minimum number of flies which transmitted the disease was one. The incubation period was 28-71 days, and all the plants developed *X* type of leaf-curl.

TABLE V

Particulars of experiments performed to transmit the disease from tomato, Lycopersicum esculentum, *to tobacco**

Serial No.	Time of experiment	Age of tobacco infected (weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
						1938-39				
(*i*)	7-9 Jan. 1939	8	10	12—32	24—48	2	$\frac{29}{48}$	35—37	20	1, *B* ?; 1, *X*
(*ii*)	10-11 Feb. 1939	8	16	6—10	24	9	$\frac{7}{24}$	20—27	56	5, *A* : 2, *X* ; other plants having traces of *X* recovered
(*iii*)	29-30 Mar. 1939	11	25	9—15	24	1	$\frac{13}{24}$	31	4	1, *X*
						1939-40				
(*i*)	16-17 Nov. 1939	9	10	5—14	21	2	$\frac{9}{21}$	22—29	20	Profuse undulations noticed on lowerleaves of infected plants
(*ii*)	4 Dec. 1939	7	10	9—24	6½	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	27 Dec. 1939	6	10	5—14	6	2	$\frac{12}{6}$	42	*Nil*	Traces of leaf-curl symptoms visible

* None of the controls developed leaf-curl disease.

TABLE VI

Particulars of experiments performed to transmit the disease from Launea asplenifolia *to tobacco* *

Serial No.	Time of experiment	Age of tobacco infected (Weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1		3	4	5	6	7	8	9	10	11
					1938-39					
(*i*)	2-3 Sept. 1938	7	6	1—25	24	2	$\frac{5}{25}$	39—46	33	1, *X*; 1 recovered
(*ii*)	10 Jan. 1939	8½	6	9—15	6	*Nil*	*Nil*	*Nil.*	*Nil*	*Nil*
(*iii*)	12-13 Feb. 1939	9	10	12—23	24	5	$\frac{12}{24}$	20—25	50	Type not formed
					1939-40					
(*i*)	28-29 July 1939	10	9	2—9	21	1	$\frac{2}{21}$	9	11	*DX*
(*ii*)	1 Sept. 1939	11	11	6—13	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	16 Sept. 1939	9	10	4—11	7	1	$\frac{6}{7}$	23	10	*C* ?
(*iv*)	16-17 Nov. 1939	9	10	9—15	22	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*v*)	7 Dec. 1939	8	9	6—12	5½	4	$\frac{6}{5\frac{1}{2}}$	35—57	44	Type not formed
(*vi*)	28 Dec. 1939	6½	10	7—13	6½	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*

* None of the controls of the various series developed leaf-curl disease.

TABLE VII

Particulars of experiments performed to transmit the disease from Sida rhombifolia *to tobacco* *

Serial No.	Time of experiment	Age of tobacco infected (Weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white flies and minimum period of feeding resulting in successful transmission (No./Hrs.)	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
					1938-39					
(*i*)	3-5 Sept. 1938	7—8	23	3—31	12—15	9	6/12	19—45	39	3, *A*; 1, *AX*; 1, *C*; 4 plants recovered
(*ii*)	12-15 Oct. 1938	8—9	24	2—25	8½—24	*Nil*	*Nil*	*Nil*	*Nil.*	*Nil*
(*iii*)	6-7 Nov. 1938	8	30	2—9	1—6	2	3/1	40—41	7	1, *CX*
(*iv*)	13-19 Dec. 1938	9	30	2—22	24	2	4/24	28—31	7	1, *CX*
(*v*)	4-7 Jan. 1939	7½	19	2—25	24—48	3	7/24	29—42	15	Type not forme
(*vi*)	8-9 Feb. 1939	8	20	4—37	19—24	6	11/19	22—27	30	1, *X*
					1939-40					
(*i*)	26-27 July 1939	10	10	3—12	5¾—22¼	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*ii*)	26-30 Aug. 1939	25	13	2—14	14—24	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	13-17 Sept. 1939	8½—9	20	2—7	7—23	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iv*)	26-30 Oct. 1939	10½	21	1—32	17—24	4	1/17	28—71	20	4, *X*
(*v*)	14-15 Nov. 1939	9	20	3—16	8½—20	2	9/20	31—45	10	1, *C*; 1, *X*
(*vi*)	6 Dec. 1939	8	10	6—10	6½	1	6/6½	28	10	*Nil*
(*vii*)	28 Dec. 1939	6	12	5—13	6½	2	12/6½	41—78	17	*Nil*
(*viii*)	4-5 Jan. 1940	7½	9	6—13	17½	2	*Nil*	*Nil*	*Nil*	*Nil*

* None of the controls of the various series developed leaf-curl disease.

It will be seen from Table VII that the maximum percentage of positive transmissions were obtained when inoculations were done during September or February. The common types of disease developed were *A* or *CX* ; a leaf of a plant suffering from latter type is shown in (Plate XVII, fig. 7). The minimum number of white flies tested and found successful for the transmission of disease was one individual and the minimum feeding period tested for the successful transmission was one hour.

It may be stated here that *Sida* was suspected to carry the leaf-curl virus of tobacco in Africa also [Storey, 1935].

Transmission of the disease from *Scoparia dulcis*

Forty-eight transmission experiments under six series, particulars of which are given in Table VIII, were performed between July and December 1939, using diseased *Scoparia* collected from the field as the source of inoculation. The age of healthy tobacco inoculated varied from 8 to 14 weeks. Only in one series (v) positive transmissions were obtained. In this, ten tobacco seedlings, about nine weeks old, were inoculated on 18-19 October each with 4-13 white-flies which had fed for 24 hours on diseased weed. Four seedlings on which 6-13 white flies had been introduced, developed leaf-curl of *X* type in 46-95 days (Plate XVII, figs. 8 and 9).

Transmission of the disease from tobacco to tobacco

In our previous investigations [Pruthi and Samuel, 1939], we found that it was not easy to transmit leaf-curl from diseased tobacco to healthy tobacco with the help of the white-fly. However, during 1939-40, we were able to get much higher percentage of successful tarnsmissions than in the past. Fifty-seven transmission experiments were performed under seven series, particulars of which are given in Table IX. In three series (i, iii and iv) positive results were obtained, the percentages of successful transmission being 8, 44 and 90 respectively. In series iv giving maximum positive results, ten inoculations were done on 16-17 November, when healthy tobacco seedlings under experiment were nine weeks old. Tobacco plant suffering from leaf-curl of *D* type was used as the source of infection. Nine plants developed leaf-curl. The general type of disease was *D*, but in some plants, it was mixed with other types. The minimum number of white-flies tested and found successful in the transmission was two.

Number of white-flies and the period of their feeding on different diseased plants necessary for the transmission of leaf-curl, the incubation period of the disease, etc.

In a previous paper [Pruthi and Samuel, 1939], it was shown that the minimum number of white-flies tested and found successful for the transmission of the disease from sunn-hemp and *Ageratum* to tobacco was 5 and 1 respectively. Similarly it was shown that the white-fly could transmit leaf-curl after five or six hours' feeding, shorter periods having not been tested. Experiments carried out during the last two years throw further light on these problems. In Table X, the minimum number of white-flies tested and found

TABLE VIII

Particulars of experiments performed to transmit the disease from Scoparia dulcis *to tobacco**

Serial No.	Time of experiment	Age of tobacco infected (weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed dis ease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
(*i*)	26-27 July 1939 .	10	9	6—12	$5\frac{3}{4}$—$22\frac{3}{4}$	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*ii*)	26 Aug. 1939 .	14	4	5—6	14	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	29-30 Aug. 1939 .	11	10	2—7	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iv*)	12 Sept. 1939 .	8	10	2—6	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*v*)	18-19 Oct. 1939 .	9	10	4—13	24	4	$\frac{6}{\frac{1}{4}}$	46—95	40	4, *X*
(*vi*)	18 Dec. 1939 .	8	5	6—10	$6\frac{1}{2}$	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*

* None of the controls of the various series developed leaf-curl disease.

TABLE IX

*Particulars of experiments performed to transmit the disease from tobacco to tobacco**

Serial No.	Time of experiment and type of source of inoculation	Age of tobacco infected (weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
(*i*)	14-15 Sept. 1939 (*AX*)	11	12	2—7	7—24	1	$\frac{2}{16}$	23	8	*X*
(*ii*)	Do. . .	9	10	1—9	7½—24	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	1-3 Nov. 1939 (*D*) .	11	9	5—16	15—21	4	$\frac{5}{15}$	67	44	3, *DX*; 1, *X*
(*iv*)	16-17 Nov. 1939 (*D*) .	9	10	7—14	21		$\frac{7}{21}$	18—24	90	2, *D*; 1, *DX*; 2, *C* & *D*; 4, *A* & *D*
(*v*)	8 Dec. 1939 (*A* & *D*) .	8	2	8—10	6½	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*vi*)	8 Dec. 1939 (*BX*) .	8	3	9—11	6½	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*vii*)	4-5 Jan. 1940 (*A* & *D*)	7	11	1—14	17½	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*

* None of the controls of the various series developed leaf-curl disease.

successful and the minimum feeding period tested which resulted in the transmission of virus in the case of various food plants are given. The minimum and maximum incubation periods and the times of respective inoculations are also stated in the table. It will be observed that in the case of a large number of food plants, e.g. *Zinnia*, *Scoparia*, *Solanum*, *Euphorbia*, *Vernonia*, *Launea*, *Sida*, only one specimen was tested, and it successfully transmitted the disease to tobacco. Similarly one specimen was enough to transmit the disease from tobacco back to zinnia. Thus it is evident that one white-fly is sufficient to transfer the leaf-curl virus to a healthy seedling. As regards the minimum feeding period necessary for successful transmission, one hour period was tested in the case of *Zinnia* and *Sida* and the disease was transmitted.

As regards the incubation period inside the inoculated plant, a perusal of Table X (columns 4 and 5) will show that the period was minimum if the inoculations were done either in July-November or in February-March. The incubation period was maximum generally in the case of inoculations which were done in December or January, though in a few cases of inoculations done in October and November the period was also maximum. Thus the experiments performed during 1938-40 confirm the conclusions arrived at in our previous paper that temperature plays an important part in the development of the disease and that low temperature suppresses the symptoms, as is the case with the ' yellow dwarf ' of potatoes [Goss and Peltier, 1925], ' curly top ' of sugar beat [Smith, 1933], tobacco mosaic [Grainger, 1936 ; Spencer, 1938], etc. Apart from air temperature affecting the plant directly, it is probable that the white-fly is most viruliferous when the temperature is moderate.

It was also observed that the feeding period remaining the same, the number of white-flies employed had no relation to the incubation period.

Transmission experiments with *Bemisia giffardi* Kotinsky

In order to ascertain as to whether any other species of *Bemisia* besides *B. gossypiperda* is also capable of transmitting the virus or viruses of tobacco leaf-curl, some inoculation experiments with *B. giffardi*, which is also common at Pusa, have been performed during the last two tobacco seasons (1938-39 and 1939-40). The only food plant on which *B. giffardi* has been so far observed at Pusa is *Jasminum sambac*. Adult specimens (25 to 55 in number) were collected from this food plant and encased, like specimens of *B. gossypiperda*, in micro-cages on the diseased tobacco plants. They, however, did not seem to feed on tobacco at all. Then cellophane cages were used for providing more space for white-flies to move about freely. Even in such cages they were indifferent to tobacco plants and eventually they died. A large number of individuals of *B. giffardi* collected from diseased jasmine plants were similarly encased on healthy tobacco plants to see if they would feed on the latter and transfer the disease to them. They were found to live only for a few hours on diseased or healthy tobacco plants without feeding on them. It may be, therefore, concluded that *B. giffardi* is not a vector of the leaf-curl virus of tobacco, and that tobacco is not a food plant of this species.

TABLE X

Minimum number of white-flies tested and found successful and minimum feeding period tested which resulted in the transmission of virus from various food plants

Host 1	Minimum No. of white-flies tested and found successful and the period they fed on diseased source in the particular experiment 2	Minimum period tested for successful transmission (hrs) and No. of white flies employed in the particular experiment 3	Minimum incubation period (days) and the time of experiment when the period was such 4	Maximum incubation period and the time of experiment when the period was such 5	Remarks 6
Zinnia to tobacco . . .	1—4½ hrs. (Oct.) .	1—3 specimens (Nov.)	18—Nov. 1938 . .	38 hrs... ...Jan. 1939 72 hrs.......Oct. 1939	
Tobacco to *Zinnia* . . .	1—18 hrs . .	18—1-5 ,, ,,	11—Aug. 1939 . .	29 hrs...... Aug. 1939	
Vernonia to *Zinnia* . . .	5—14 hrs . .	14—5-7 ,, ,,	21—Aug. 1939 . .	23 hrs.......Aug. 1939	Only one set of experiments performed (Aug. 1939)
Scoparia to *Zinnia* . . .	1—22 hrs . .	22—1-5 ,, ,,	15—Aug. 1939 . .	34 hrs.......Aug. 1939	
Euphorbia to *Zinnia* . .	2—20 hrs . .	20—2-5 ,, ,,	27—Aug. 1939 . .	......	
Zinnia to *Zinnia* . . .	1—18 hrs . .	18—1-10 ,, ,,	11—Aug. 1939 . .	29 hrs.......Aug. 1939	
Solanum to tobacco . .	1—8 hrs (July and Nov.).	4½—7 specimens (Dec.)	11—July 1938 . .	48 hrs.......Dec. 1939	
Euphorbia to tobacco . .	1—23 hrs (July) .	6—2 specimens (Dec.)	10—July 1938 . .	64 hrs.......Oct. 1939	
Vernonia to tobacco . .	1—38 (Sept.) . .	6—9 specimens (Oct.)	14—July and Oct. 1938	50 hrs.......Jan. 1939	
Tomato to tobacco . . .	7—24 (Feb.) . .	6—12 specimens (Dec.)	20—Feb. 1939 . .	42 hrs.......Dec. 1939	
Launea to tobacco . . .	2—21 (July) . .	5½—6 specimens (Dec.)	9—July 1939 . .	57 hrs.......Dec. 1939	
Sida to tobacco . . .	1—17 (Oct.) . .	1—3 specimens (Nov.)	19—Sept. 1939 . .	78 hrs.......Dec. 1939	
Scoparia to tobacco . . .	2—24 . . .	7—16 . . .	15—Sept. 1939 . .	95 hrs.......Oct. 1939	
Tobacco to tobacco . . .	2—16 (Sept.) . .	15—5 . . .	18—Nov. 1939 . .	67 hrs.......Nov. 1939	

Discussion and conclusions

From the foregoing account it will be evident that a large variety of cultivated plants and weeds are alternate hosts of tobacco leaf-curl, and that the white-fly, *B. gossypiperda*, can easily transmit the disease from a large number of them to tobacco. Besides sann-hemp and *Ageratum conyzoides*, which have already shown to be very important alternate hosts [Pruthi and Samuel, 1939], in the case of the following plants transmission experiments have generally given over 50 per cent positive results, and therefore they can be definitely considered to harbour leaf-curl virus or viruses : *Zinnia elegans*, *Solanum nigrum*, *Euphorbia hirta*, *Vernonia cinerea*, *Lycopersicum esculentum*. In addition to these, *Launea asplenifolia*, *Sida rhombifolia* and *Scoparia dulcis* also appear to be alternate hosts of the disease as the percentage of positive transmission from them was sometimes 40-45.

As regards the actual sources of leaf-curl infection to tobacco in the field, it does not necessarily follow that all the plants named above are sources of danger to this crop. To determine the real sources, one has to consider the time of the year when the above plants occur in the field and the time when they show the incidence of the disease, remembering that tobacco is most susceptible to infection from September up to the end of November [Pruthi and Samuel, 1937, 1939]. Though our experiments reported in the present paper show that tobacco can get infected during spring (February-March) also, if it is not more than about ten weeks old, it is only of academic interest as in actual practice the tobacco crop in North Bihar is generally harvested in January-February and, if it is still standing, only young leaves of the offshoots get diseased.

In Fig. 2, the seasonal histories of tobacco and the various alternate hosts of leaf-curl are diagrammatically shown. The diagram shows 11 concentric circles divided into 12 equal parts to represent the different months of the year, and each circle is designed to represent a particular host plant. Sunn-hemp, *Agertarum conyzoides* and *Zinnia elegans*, which are alternate hosts of tobacco leaf-curl, have been shown by us to have alternate hosts of their own disease. For example, in the case of sunn-hemp, *Ageratum conyzoides* and *Euphorbia hirta* are such hosts and diseased sunn-hemp is also a definite source of infection for healthy sun-hemp. Such alternate host plants are, therefore, shown in the background of sunn-hemp. In the same way, tobacco, *Vernonia*, *Scoparia*, *Euphorbia* and *Zinnia* are all shown in the circle for *Zinnia*, showing that infection from them can go to healthy *Zinnia*. Similarly *Ageratum*, besides having diseased *Ageratum* as a source of infection, has sunn-hemp and tobacco as alternate hosts.

In the case of tobacco, the large number of alternate host plants, which have been enumerated already, are shown in the circle for this crop. A glance at the calendar shows that during the four months of February-May, practically no alternate host plant exists in the field, and there is no tobacco crop in the field or nurseries between June and the middle of August. Therefore, the alternate hosts actually dangerous to tobacco are those which show the disease in August-November.

The garden zinnia, in the case of which the white-fly has been shown to transmit the disease very readily, shows leaf-curl in the field during August-October, and thus diseased zinnia is an important source of danger to tobacco

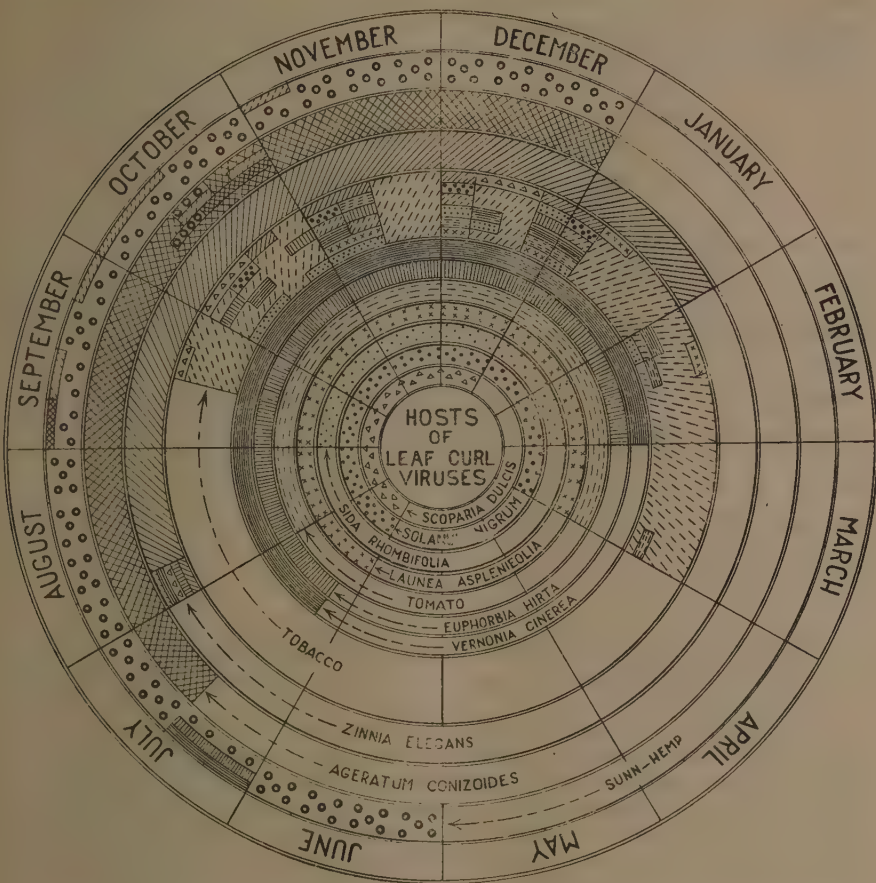


FIG. 2. Seasonal histories of tobacco and various alternate hosts of leaf-curl

crop, like sunn-hemp and *Ageratum* which too have been shown such as stated above. Similarly, *Vernonia*, *Solanum nigrum* and *Euphorbia* are sources of danger during October and November and tomato and *Launea* in November and December.

As a result of our previous investigations [Pruthi and Samuel, 1937; 1939], we showed that tobacco suffers from several types of leaf-curl, designated *A*, *B*, *C*, *D* and *X*, of which *A* and *D* are also found in sunn-hemp and *Ageratum* from which they can be easily transmitted to tobacco by the white-fly. The additional plants which have been shown to be alternate hosts of tobacco leaf-curl in the present paper have in some cases given rise to different types of the disease in tobacco. The types which are caused when the various

plants are used as sources of infection are stated in column 11 of Tables I-IX and the information is summarized below :—

Source	Type of disease developed on tobacco
Zinnia elegans	C, D and X
Solanum nigrum	B, C, D, all the three often mixed with X
Euphorbia hirta	B, in a few cases C, both often mixed with X
Vernonia cinerea	A and C, both mixed with X
Lycopersicum esculentum	A
Launea asplenifolia	X, sometimes DX also
Sida rhombifolia	C, sometimes A also
Scoparia dulcis	X

Thus it will be observed that we have discovered at least one alternate host for each type of leaf-curl disease of tobacco. Probably there are several hosts for each type.

In our previous papers [Pruthi and Samuel, 1937 ; 1939], we showed that the tobacco crop is most susceptible to infection from September up to the middle of November. In the investigations reported in this paper, the maximum percentage of successful transmission with various alternate plants (see column 10 of tables) was also obtained during the months named above. Transmission experiments performed during July and August and again in February with 8-10 weeks old tobacco seedlings also gave a very high percentage of successful results, but this is of not much practical importance because, as already stated, tobacco is not in the field till September, and by February it gets harvested or if standing its young offshoots only get the infection.

From the foregoing it will be observed that to attempt to control the leaf-curl disease of tobacco by the eradication of its various alternate host plants is a very laborious if not impracticable work. The alternative methods of control are to evolve resistant varieties or to check the white-fly vector by means of dusting and spraying at suitable times of the season. We have done some work on the latter method and the results are very encouraging. During the next season we propose to try this method on a field scale and will report the results in due course.

It is noteworthy that with another species of white-fly, viz. *B. giffardi* which is also common at Pusa, no successful transmission was obtained in the case of any plant. In fact it did not feed on tobacco at all.

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STUDIES ON THE ROOT-ROT DISEASE OF COTTON IN THE PUNJAB

IX. VARIETAL SUSCEPTIBILITY TO THE DISEASE

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The most destructive disease of cotton in the irrigated parts of this province is cotton root-rot. The disease becomes active during the months of June and July soon after the first irrigation when the plants are about four to six weeks old, and usually results in extremely heavy losses to the crop.

It has already been reported that cotton root-rot is caused by *Rhizoctonia solani* and *R. bataticola*.* The disease flourishes in the presence of excessive moisture and high summer temperatures (1937, 1939).

During the investigation of control measures for the disease a thorough search has been made for a variety which might be immune or resistant to the disease. In this connection almost all the important Indian types and a very large number of foreign types obtained from different cotton-growing countries of the world have been tested in the past seven years for their resistance to root-rot. The results of these trials are recorded in this paper.

Method

The susceptibility of various varieties and selections was tested in highly and uniformly infected plots which had been under observation for several years. The tests were conducted at Lyallpur where climatic and soil factors are very favourable for the progress of the disease. Prior to the field selection of varieties the plot of land was sown with local cottons which are known to be highly susceptible to the disease for two or three seasons to ensure uniform spread of the disease in the entire plot, as this is necessary to obtain reliable and comparable data. The varieties to be tested were sown at the optimum time for the occurrence of the disease, i.e. during the month of May.

* *Rhizoctonia bataticola* = C Strain of Haigh = *Macrophomina phaseoli*

Experimental results

Varietal susceptibility

(a) *Susceptibility of Punjab cottons to root-rot*

To begin with only important Punjab varieties were tested for their susceptibility to root-rot. The degree of their susceptibility was determined by sowing them in a heavily infected field. The various varieties were sown in such a way that they were all uniformly distributed over the whole plot. The death rate counts were taken at weekly intervals throughout the cotton season. The dead plants were pulled out and examined for root-rot symptoms and, if there was any doubt as to the cause of death in any plant, isolation of the organism was resorted to. The actual position of the plants which had been killed was indicated in the field by cotton sticks which had been previously dipped in coal tar to safeguard against the attack of white ants. This method facilitated checking of the counts at different periods during the root-rot season which extends from June to October.

The susceptibility tests were conducted in two different plots. In one plot four varieties of *desi* (*G. indicum*) and three of American (*G. hirsutum*) and in the second plot six of American and one of *desi* cottons were tested. The results of these experiments are summed up in Table I. As the two experiments were conducted in different fields, the results of the two experiments are not comparable with each other.

Table I

Susceptibility of some Punjab cottons to root-rot

Plot I					Plot II				
Variety	Species	Total No. of plants	Plants killed	Per cent root-rot mortality	Variety	Species	Total No. of plants	Plants killed	Per cent root-rot mortality
4 F	*G. hirsutum*	289	114	39·44	LSS	*G. hirsutum*	557	237	42·55
15	*G. indicum*	298	146	48·99	43 F	Do.	622	245	39·99
289 F	*G. hirsutum*	276	136	48·74	45 F	Do.	490	189	38·57
10	*G. neglectum*	251	132	52·54	Jubilee cotton	(Million Dollar × Mollisoni 15)	594	184	30·89
50	*G. indicum*	247	138	55·87	58 F	*G. hirsutum*	640	272	42·50
12	*G. sanguineum*	248	141	56·85	15	*G. indicum*	727	252	34·66
43 F	*G. hirsutum*	267	158	59·20	4 F	*G. hirsutum*	611	229	37·48

The data given in Table I show that all the varieties tested are highly susceptible to the disease. In another season seven more Punjab varieties, i.e. Mollisoni 39, 41, 46 F, 47 F, 289 F, 83 AF and 38 F were tested, the first two varieties being *desi* and the remaining five being American. The mortality records were taken throughout the season and it was found that all the varieties succumbed to the disease to more or less the same degree, and results quite similar to the above were obtained.

Such tests with the Punjab varieties were repeated during a number of seasons and no variety showed any appreciable resistance to the disease. In certain seasons the average percentage of mortality in the cottons tested was extremely high being 60-80 per cent.

(*b*) *Susceptibility of cottons from other Indian provinces*

All the Punjab cottons having been found highly susceptible to root-rot disease, a number of important types from other provinces in India were obtained in order to find out if any of those varieties was resistant to the disease. The first lot of these varieties was tested in 1937 in a heavily infected plot. The middle of May is the optimum for the occurrence of the disease. The sowings were done on 22 May. Eight varieties were tested and four repeats of each variety were kept. Two Punjab varieties were sown as controls for comparative purposes. The results of these tests are given in Table II.

TABLE II

Susceptibility of cottons from other Indian provinces to root-rot

Variety	Species	Source	Total plants	Plants killed	Average per cent root-rot mortality	Root-rot mortality range
V 438 .	*G. arboreum* . .	Central Provinces . .	157	124	84·8	68·6—90·7
Bani 306 .	Do. . .	Do. . .	153	129	84·7	73·7—97·1
V 434 .	Do. . .	Do. . .	164	134	81·7	72·7—95·5
E B 31 .	Do. . .	Do. . .	119	99	67·3	89·1—90·0
Late verum	Do. . .	Do. . .	166	140	84·5	80·0—95·0
C 520 .	Do. . .	United Provinces . .	144	105	72·2	62·5—81·1
C 402 .	Do. . .	Do. . .	110	76	67·0	84·4—88·5
Cambodia cotton	*G. hirsutum* . .	Bombay . . .	124	38	70·6	57·7—83·3
4 F . .	Do. . .	Punjab (control) . .	191	141	73·7	66·0—82·0
43 F . .	Do. . .	Do. . .	158	122	77·0	70·6—82·1

The results given above show that all the eight varieties tested are susceptible almost to the same degree as the Punjab cottons.

Some more samples of cotton seeds were obtained from other cotton-growing parts in India during 1938 and 1939 and subjected to field trials at Lyallpur. Results similar to the above were obtained, showing thereby that all the Indian varieties tested are highly susceptible to root-rot. The results of such tests, conducted in 1939, showing percentage of root-rot mortality are summed up in Table III.

TABLE III

Susceptibility of Indian cottons to root-rot in the Punjab

Serial No.	Variety or strain	Species	Source	Average per cent mortality	Maximum per cent mortality observed
1	Gaorani 4B-5	*G. arboreum*	Nizam's Dominions (Hyderabad)	94·1	100·0
2	Gaorani 6	*G. arboreum*	Do.	98·3	100·0
3	Gaorani 12F	*G. arboreum*	Do.	97·2	100·0
4	Gaorani 113	*G. arboreum*	Do.	72·5	100·0
5	Cutchica 9	*G. arboreum*	Do.	84·9	100·0
6	Parbhani-American	*G. hirsutum*	Do.	65·7	79·4
7	Perso-American	*G. hirsutum*	Cawnpore (U. P.)	48·9	69·4
8	Rozi	*G. arboreum*	Baroda State	55·7	77·7
9	Karkhadi (Bulk general) (unselfed)	*G. arboreum*	Do.	71·0	81·8
10	Karkhadi Family No. 12	*G. arboreum*	Do.	65·1	71·4
11	Karkhadi Family No. 15	*G. arboreum*	Do.	95·2	100·0
12	Karkhadi Family No. 18	*G. arboreum*	Do.	77·6	92·8
13	Karkhadi Family No. 26	*G. arboreum*	Do.	71·2	78·6
14	Strain Co 2	*G. hirsutum*	Coimbatore (Madras)	67·5	83·3
15	Strain 920	*G. hirsutum*	Do.	62·0	75·0
16	Kampala bulk (Naked)	*G. hirsutum*	Do.	54·5	69·2
17	Jinja bulk (Naked)	*G. hirsutum*	Do.	38·5	58·3
18	× 3915 Q, Cambodia × Uganda	*G. hirsutum*	Do.	77·9	100·0
19	× 4463 B2, Cambodia × Uganda	*G. hirsutum*	Do.	54·4	72·7
20	× 4383 B, Uganda × Cambodia	*G. hirsutum*	Do.	54·6	100·0
21	Bourbon (*G. religiosum*)		Do.	39·2	46·1
22	Nadam bulk	*G. arboreum*	Coimbatore (Madras)	92·8	100·0
23	*Neglectum roseum* bulk	*G. arboreum*	Do.	81·6	100·0
24	No. 4714 Cocanadas × (N 14 × *Cernuum*)	*G. arboreum*	Do.	91·5	100·0
25	No. L3 4/4 Reselection from 4714	*G. arboreum*	Do.	87·8	100·0
26	No. c 6/3 Natural cross in N × *Cernuum*	*G. arboreum*	Do.	80·7	100·0
27	Karunganni K I	*G. arboreum*	Koilpatti (Madras)	95·2	100·0
28	Nandyal 14	*G. arboreum*	Nandyal (Madras)	95·8	100·0
29	Cocanadas 171	*G. arboreum*	Guntur (Madras)	100·0	100·0
30	83 A F (*G. hirsutum*)		Punjab	68·3	80·7
31	Uppam 2919	*G. herbaceum*	Hagari	90·4	100·0
32	Western H I	*G. herbaceum*	Do.	94·4	100·0
33	Strain 19	*G. herbaceum* × *G. arboreum*	Mysore State	86·3	100·0
34	H 190	*G. herbaceum* × *G. arboreum*	Do.	91·7	93·3
35	Nadam-like	*G. herbaceum* × *G. arboreum*	Do.	81·9	90·9
36	*Cernuum* Nadam 86 (*G. cernuum* × *G. obtusifolium*)		Do.	78·8	91·1
37	M A_2 (Upland cotton × Peruvian tree cotton)		Do.	82·0	96·6
38	Mollisoni 39 (*G. indicum*)		Punjab	74·5	100·0

(c) Susceptibility of foreign cottons

As there appeared to be little chance of picking up a resistant or a partially resistant type from Indian cottons, six samples of cotton seed were obtained from America in 1937 and a preliminary test conducted in order to determine their susceptibility to root-rot. The mortality percentage in the six American samples varied from 19 to 38 as against 74 per cent in the Punjab American cotton (43 F). The number of plants tested for each variety was, however, extremely small being 25-44. To confirm the above findings, these samples were again tested in the field in 1938. This time about 100 plants of each were kept. All the samples were found to be severely attacked and showed a maximum mortality of 52-93 per cent, showing thereby that these foreign types had somehow escaped a severe attack in the first season. All the same it was considered worth while to test a wide range of exotic cottons, and seed of a large number of foreign varieties was imported and trials conducted in 1938. As the number of varieties was fairly large, these had to be tested in two separate plots. Seventeen samples with Punjab 4 F control were sown in one plot and the remaining 95 with two Punjab cottons as controls were sown in another plot. Three repeats comprising 100-120 plants of each of the samples were kept and mortality counts made at weekly intervals throughout the season. The data of these tests conducted in 1938 in two different plots are recorded in Tables IV and V.

The results recorded show that all the samples tested suffered a heavy loss due to root-rot and none of the types showed marked resistance to the disease. Most of the types opened badly and produced immature seed which failed to germinate; others produced seed in which the percentage of germination as tested in the laboratory was extremely low, i.e. below 11 per cent.

All the same, certain varieties which showed a maximum mortality up to 40 per cent and produced some viable seed were subjected to a further test. The selfed seed of individual plants was sown in separate rows in 1939 in a heavily and uniformly infected plot. The progeny of all the plants of various varieties was severely attacked by root-rot, mortality being 53-77 per cent, showing thereby that the material was highly susceptible and could be safely discarded.

Similar tests with exotic cottons were carried out in 1939 with the fresh material obtained from various cotton-growing countries and in addition some of the last year's samples were also included in these trials. The data are tabulated in Table VI.

Most of the varieties were severely attacked by root-rot, but the others were less severely attacked and the range of maximum mortality varied from 26 to 42 per cent. Some of these had shown extremely high mortality in 1938 and were therefore discarded, whereas the remaining nine were selected and tried in 1940, but all were found to be susceptible.

Resistance of individual plants to the disease

The disease invariably appears in patches and a few healthy looking plants may be seen scattered here and there in the diseased patch. These plants grow to their full size and yield almost as well as those plants which

TABLE IV

Susceptibility of some foreign cottons to root-rot (1938)

Serial No.	Variety or strain	Species	Source	Average per cent mortality	Maximum per cent mortality observed
1	Z 14 . . .	G. hirsutum.	Zomba, Nyasaland .	33·8	57·9
2	C 28 . . .		Do. .	42·2	66·6
3	N 3 . . .		Do. .	35·5	46·4
4	N 10 . . .		Do. .	41·0	55·2
5	U 4.4.2. . .		Do. .	59·5	73·3
6	Lonestar Lot 33		Brisbane, Queensland	35·9	53·3
7	Lonestar Lot 34		Do. .	32·0	44·4
8	Miller Lot 42		Do. .	31·6	61·1
9	Cliett . .		Do. .	29·9	40·0
10	Mebane . .		Do. .	55·9	67·9
11	New Boykin .		Do. .	55·9	58·3
12	Stoneville . .		Washington . .	33·8	48·3
13	Acala Shafter .		Do. . .	37·8	50·0
14	Coker, Cloveland		Do. . .	33·1	37·0
15	Coker's Farm, Relief No. St. 3		Do. . .	36·6	56·6
16	D. & P. L-11 .		Do. . .	41·1	46·6
17	Mebane, Triumph		Do. . .	40·5	51·7
18	4F . .		Punjab (control) .	59·7	72·4

TABLE V

Susceptibility of foreign cottons to root-rot (1938)

Serial No.	Variety or strain	Species	Source	Average per cent mortality	Maximum per cent mortality observed	Serial No.	Variety or strain	Species	Source	Average per cent mortality	Maximum per cent mortality observed
1	U/4 Bulk	G. hirsutum	Morogoro, Tanganyika Territory	29·2	43·5	23	920	G. hirsutum	Barberton, Transvaal	32·1	42·1
2	U/4/4		Do.	41·5	65·0	24	921		Do.	42·8	64·7
3	998		Do.	43·4	77·0	25	052		Do.	27·6	43·2
4	7 L 6		Gatooma, South Rodesia	25·1	46·1	26	95		Do.	30·3	33·3
5	7 L 7		Do.	27·4	42·1	27	5149		Do.	0·5	40·0
6	7 L 10		Do.	35·7	52·6	28	998 R		Do.	25·0	35·0
7	7 L 24		Do.	46·6	60·0	29	B × 172		Sigatoka, Ginnery	58·2	64·3
8	G, 5·136		Do.	54·7	61·6	30	Allen		Ibadan, Nigeria	53·3	77·5
9	Giza 12	G. peruvianum	Giza, Egypt	44·4	56·4	31	514 D		Sudan	58·1	75·0
10	Giza 19		Do.	64·3	78·9	32	XA 129		Do.	65·8	79·5
11	Giza 26		Do.	65·2	89·2	33	XA 1129		Do.	61·7	72·5
12	Giza 7		Do.	51·6	78·4	34	511 C		Do.	54·8	76·3
13	Sakha 4		Do.	62·0	73·0	35	Gadag No. 1		Do.	82·0	89·2
14	Sakha 7		Do.	67·1	75·7	36	39 Mollisoni	(G. indicum)	Punjab (control)	83·2	89·5
15	365	G. hirsutum	Morogoro, Tanganyika Territory	45·6	71·8	37	83 A F	G. hirsutum	Do.	68·1	89·2
16	530		Do.	52·1	76·3	38	Missdel 7		Greenville, Mississippi	65·0	87·5
17	244		Do.	40·3	57·5	39	Paymaster		Texas	41·2	48·7
18	No. 553		Do.	65·[illegible]	75·0	40	Rhyne's Cook		Alabama	49·5	62·8
19	Local		Do.	54·2	72·5	41	Missdel 1-0539		Greenville, Miss.	46·5	54·5
20	B P 52		Uganda, Africa	49·2	57·5	42	Mebane		Lockhart, Texas	57·2	92·5
21	B P 79		Do.	38·3	57·5	43	Chapman, Ranch, Mebane		Texas	44·4	37·5
22	U B 24/4		Do.	37·0	42·5	44	Rowden 2088		Scott, Arkansas	37·9	40·0

45	Harper	G. hirsutum	Martindale, Texas	47·7	55·3
46	Cliett	G. hirsutum	San Marcos, Texas	40·0	50·0
47	Mebane 140	G. hirsutum	Chillicothe, Texas	29·1	40·0
48	Mebane 804-50	G. hirsutum	Beeville, Texas	49·5	55·0
49	Mebane 141	G. hirsutum	Chillicothe, Texas	66·6	72·4
50	Jennings	G. hirsutum	Plain View, Texas	43·9	52·8
51	Cluster	G. hirsutum	Austwell, Texas	59·2	79·5
52	Bagley	G. hirsutum	Martindale, Texas	58·7	65·0
53	Missdel, 4-91168	G. hirsutum	Greenville, Miss.	44·9	61·5
54	Delfos 719	G. hirsutum	Stoneville, Miss.	47·0	57·5
55	Delfos 513 B	G. hirsutum	Do.	28·4	40·0
56	Stoneville 2 B	G. hirsutum	Do.	36·0	53·8
57	Stoneville 4 A	G. hirsutum	Do.	45·1	61·9
58	Stoneville 5 A	G. hirsutum	Do.	47·1	76·5
59	Missdel 6	G. hirsutum	Greenville, Miss.	47·0	71·8
60	Aldridge	G. hirsutum	Planc, Texas	42·8	51·4
61	Texas, Special	G. hirsutum	Itasca, Texas	52·7	65·0
62	Wacona	G. hirsutum	Waco, Texas	54·3	67·6
63	New Boykin	G. hirsutum	Howe, Texas	50·8	62·5
64	Northern Star	G. hirsutum	Waco, Texas	34·9	38·9
65	Webb's Purple	G. hirsutum	Union City, Okla.	35·8	50·0
66	Hurley, Special	G. hirsutum	Cooper, Texas	49·9	52·5
67	Arkansas 17	G. hirsutum	Marianna, Ark.	49·5	53·8
68	Half & Half	G. hirsutum	B F Summerour Seed Co ; Narcross G A	49·1	55·0
69	Oklahoma Triumph	G. hirsutum	Stillwater, Okla.	49·1	62·5
70	Rog-ers, Acala	G. hirsutum	Navasota, Texas	37·2	42·5
71	Caddo	G. hirsutum	Waco, Texas	44·2	53·8
72	Ferguson 406	G. hirsutum	Howe, Texas	38·1	48·6
73	Sunshine	G. hirsutum	Mekinney, Texas	47·9	60·0
74	Kasch	G. hirsutum	San Marcos, Texas	47·7	52·9
75	Bryant Mebane	G. hirsutum	Corsicana, Texas	48·9	65·0
76	Watson	G. hirsutum	Garland, Texas	21·7	31·0
77	Mebane	G. hirsutum	Lockhart, Texas	53·5	59·3
78	Lonestar	G. hirsutum	Tivoli, Texas	40·7	42·5
79	Qualla	G. hirsutum	San Marcos, Texas	44·3	51·3
80	D & P L 11 A	G. hirsutum	Scott, Miss.	46·0	55·5
81	Roldo Rowden	G. hirsutum	Scott, Arkansas	45·5	52·8
82	Paris Bigboll	G. hirsutum	Paris, Texas	41·2	56·4
83	Bennett's	G. hirsutum	Bryan, Texas	45·7	70·0
84	Acala, N 28-5	G. hirsutum	U. S. Field Station, State, College, N. M.	36·8	45·5
85	Lankart	G. hirsutum	Waco, Texas	47·5	57·5
86	Startex	G. hirsutum	College, Station, Texas	48·2	70·2
87	Wild's Semiwilt resistant strain 2	G. hirsutum	Hartsville, S. C.	51·7	70·0
88	Mebane	G. hirsutum	Troy, Texas	52·7	54·5
89	Lenty Acala	G. hirsutum	Austwell, Texas	50·6	67·6
90	Worley, Boykin	G. hirsutum	Rockdala, Texas	63·8	71·0
91	Union	G. hirsutum	San Marcos, Texas	43·5	47·1
92	Olander, Mebane	G. hirsutum	Hutto, Texas	58·2	75·0
93	Lonestar	G. hirsutum	Waco, Texas	44·4	51·4
94	Texas Mammoth	G. hirsutum	Knapp, Texas	43·2	54·1
95	Russell	G. hirsutum	Annona, Texas	37·2	61·5

TABLE VI

Susceptibility of exotic cottons to root-rot (1939)

Serial No.	Variety or strain	Species	Source	Average per cent mortality	Maximum per cent mortality observed
1	Sea Island	(*G. barbadense*)	Cotton Suva (Figi)	41·9	60·0
2	Mebane	*G. hirsutum*	Brisbane	35·2	38·4*
3	Indo Acala	*G. hirsutum*	Do.	21·8	50·0
4	Half & Half	*G. hirsutum*	Do.	21·7	24·3*
5	Cliett	*G. hirsutum*	Do.	34·2	45·4
6	Ferguson	*G. hirsutum*	Do.	23·3	34·3
7	New Boykin	*G. hirsutum*	Do.	32·9	37·5
8	Lonestar (L S 31-5-1-1-2-0)	*G. hirsutum*	Do.	39·3	42·1
9	Lonestar progeny (L S 30-2-4-3-0-1-0)	*G. hirsutum*	Do.	29·0	37·5
10	Lonestar progeny (L S 31-5-0-0-1-0)	*G. hirsutum*	Do.	34·1	41·6
11	Miller 42	*G. hirsutum*	Do.	24·2	30·0*
12	Miller 41	*G. hirsutum*	Do.	23·5	32·4†
13	Mesowhite	*G. hirsutum*	Cyprus (Nicosia)	43·3	70·0
14	Coker 100	*G. hirsutum*	Do.	48·8	71·4
15	Clevewilt 5	*G. hirsutum*	Do.	36·5	62·5
16	Titsiros	(*G. barbadense*)	Do.	50·0	75·0
17	Triumph	*G. hirsutum*	Do.	47·1	68·5
18	998	*G. hirsutum*	Nairobi (Kenya)	34·6	42·8
19	9243	*G. hirsutum*	Do.	23·8	27·5†
20	U/4	*G. hirsutum*	Do.	26·2	27·2*

Serial No.	Variety or strain	Species	Source	Average per cent mortality	Maximum per cent mortality observed
21	Rhyne's Clevewilt	*G. hirsutum*	Arkansas	30·8	32·2†
22	Clevewilt 6	*G. hirsutum*	Do.	33·7	42·8
23	Dixtri	*G. hirsutum*	Do.	26·6	33·3†
24	Coker Clevewilt strain 4	*G. hirsutum*	Do.	51·4	57·8
25	Dixit	*G. hirsutum*	Do.	50·3	63·6
26	C-28	*G. hirsutum*	Salima, Nyasaland	20·4	30·5*
27	Z-14	*G. hirsutum*	Do.	25·6	27·2*
28	N-10	*G. hirsutum*	Do.	25·2	26·6*
29	U/4/4/2	*G. hirsutum*	Tanganyika	33·1	42·4†
30	Local	*G. hirsutum*	Do.	19·7	22·5*
31	9264	*G. hirsutum*	Barberton, Transvaal	28·2	47·2
32	5143	*G. hirsutum*	Do.	25·5	36·3†
33	920	*G. hirsutum*	Do.	17·8	22·5*
34	Bancroft	*G. hirsutum*	Do.	33·2	44·0
35	Delta & Pineland-12	*G. hirsutum*	Texas, U. S. A.	30·3	53·3
36	Rowden 2088	*G. hirsutum*	Do.	31·2	36·3†
37	Delfos 130	*G. hirsutum*	Do.	17·9	26·0†
38	Chinese Million-Dollar (Yellow Flower)	(*G. arboreum*)	Punjab	57·7	78·9

39	Russian 2284	G. hirsutum	Coimbatore	47·8	54·5
40	Durango	G. hirsutum	Do.	52·9	61·5
41	Lonestar	G. hirsutum	Do.	43·9	58·8
42	Acala Ardmone	G. hirsutum	Do.	53·0	81·8
43	Hartsville	G. hirsutum	Do.	47·9	100·0
44	Western Wonder	G. hirsutum	Do.	46·3	83·3
45	Uganda Z 1/9	G. hirsutum	Do.	53·4	76·9
46	Uganda A 12	G. hirsutum	Do.	45·8	57·1
47	Quenbradinho (South America)	G. barbadense	Do.	56·9	80·0
48	Verdao (South America)	G. barbadense	Do.	87·0	100·0
49	Giza 12	(G. peruvianum)	Do.	59·7	66·6
50	Sakel (Egyptian)	G. barbadense	Do.	80·5	100·0
51	Ashmoni (Egyptian)	G. barbadense	Do.	70·0	75·0
52	Hopi-3 (Washington)	G. religiosum	Do.	80·8	87·4
53	Moco (South America)	G. religiosum	Do.	84·5	91·6
54	Ishan-A	(G. barbadense)	Ibadan (Nigeria)	73·8	100·0
55	Sokoto	(G. religiosum)	Do.	94·5	97·5
56	Bauchi	(G. barbadense)	Do.	78·0	88·0
57	Washington (Delfos 719)	G. hirsutum	Washington	32·5	50·0
58	Coker Clevewilt Str. 7	G. hirsutum	Do	35·5	50·0
59	Coker Farm Relief Str. 5	G. hirsutum	Do.	28·8	35·4†
60	Stoneville 2B	G. hirsutum	Do.	31·6	50·0
61	Delta pine A (D & Pl 11 A)	G. hirsutum	Do.	30·3	42·4
62	Acala (Shafter)	G. hirsutum	Do.	25·8	34·6*
63	Coker 100 Strain 2	G. hirsutum	Do.	36·1	50·0
64	Acala (Roger's)	G. hirsutum	Do.	22·8	33·3*
65	Coker wild's Strain [illegible]	G. hirsutum	Do.	31·8	43·4
[illegible]	Mollisoni 39	(G. indicum)	Punjab	74·5	100·0

* High mortality in 1938

† Selected for further trials

are found growing in a disease-free area. Sometimes when two plants are growing at the same spot only one of them might succumb to root-rot, whereas the other appears to be healthy and seems to flourish like normal plants in disease-free fields throughout the season.

In order to find out whether these plants which escaped root-rot in diseased patches or those whose companion plant had died of root-rot attack are comparatively resistant to root-rot, experiments were conducted by selfing the flowers of such plants and testing the seed in the following season in a heavily infected plot. In this connection selection of plants was made as follows :—

(*i*) *Plants that escaped mortality in a heavily diseased plot*

Such selections which were made in the Farm area were selfed, whereas the selections made in zemindar's fields were not selfed. The selections were continued to be made from 1934 to 1939 and tested from year to year. In several cases such tests were conducted up to the third generation, but none of these selections gave indication of resistance to the disease.

Selections were also made from some of the foreign varieties and their selfed seed tested for resistance to root-rot. Progenies of all such selections were found to be highly susceptible.

(*ii*) *Plants whose companion plant had died of root-rot*

In a field 100 ft. × 212 ft. severely affected with root-rot *desi* cotton (Mollisoni 15) was sown in rows 3 ft. apart in 34 lines. About four cotton seeds were dibbled at a distance of every 2 ft. along the line. After germination had taken place two plants were kept in each hole in all the even lines, whereas single plants were maintained in a spot in all the odd lines so that single plant lines and double plant lines alternated throughout the plot.

Mortality counts were taken at weekly intervals throughout the season. The plants whose companion plant (growing in the same spot) had died of root-rot in the even lines were selected and their selfed seed tested under heavy conditions of infection in the field in the following season, but no indication whatsoever of resistance to the disease was obtained.

(*iii*) *Plants which wilt and then recover*

It has been observed that a plant here and there may wilt due to root-rot and then recover during irrigation, cool nights or wet weather. Though such recoveries are very rare, yet it was considered worth while to investigate whether progenies of such recovered plants showed any resistance to the disease. Selfed seed of a number of recovered plants was tested as usual in the following season along with controls and it was observed that progenies of all such selections suffered as heavy a loss due to root-rot as the controls.

(*iv*) *Plants with heavily and partially attacked roots*

Healthy looking plants of both *desi* and American varieties were selected from diseased fields and their seed selfed. The roots of these plants were examined after the crop was over and found to be heavily attacked, partially attacked and almost healthy. In the following season the selfed seed of

these three lots was tested for resistance to root-rot separately and a single line was sown with the seed obtained from each plant. The trials were controlled by sowing lines of 4 F (*G. hirsutum*) and Mollisoni 15 (*G. indicum*). No indication of any appreciable resistance of the progeny to the disease was obtained.

(*v*) *Selections from mixed cottons*

As no evidence of resistance of any pure type to the disease was forthcoming, it was considered that there might be some scope for picking up a resistant type from the fields of mixed and unselected varieties of cotton. An attempt was made along these lines and seed from the mixed population of those farmers' crop who had not taken up pure strains of cottons was collected. Seed of both mixed *desi* and American cottons was obtained from different zemindars in the province including certain submontanous tracts where root-rot is practically absent. The samples were tested in a heavily infected plot and the mortality records taken throughout the season. The extent of attack in these samples was as great as in the pure type controls.

There is enough experimental evidence to show that the material so far tested is highly susceptible to the disease even under infection conditions present in the field which are by no means extremely severe. It was therefore not considered worth while to subject the material to further tests under controlled optimum conditions of infection.

Summary

1. A very large number of varieties of cottons, both indigenous and exotics, have been tested with a view to finding a type resistant to root-rot disease in the Punjab. None of the varieties tested has shown any appreciable resistance to the disease.

2. Selfed seeds of apparently healthy plants in diseased plots did not yield resistant plants.

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STUDIES ON THE ROOT-ROT DISEASE OF COTTON IN THE PUNJAB

X. EFFECT OF CERTAIN FUNGI ON THE GROWTH OF ROOT-ROT FUNGI

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(With Plates XIX and XX and two text-figures)

IN a preceding number of this series [Vasudeva, 1936] it was shown that two *Rhizoctonia* species and a number of other fungi appeared frequently when isolations were made from diseased cotton roots. It was also indicated that the parasitic activity of *Rhizoctonia solani* is enhanced when it acts in combination with certain other fungi.

Experiments have now been conducted to find out whether there existed any conditions in which the growth of the parasitic fungi, *R. solani* and *R. bataticola*, could be reduced. Certain conditions under which it occurs have been investigated and are described in this paper.

Experimental

A. Fungi and media used

The following fungi were used during the course of this investigation.

Fungus	Source
Rhizoctonia solani Kuhn	Isolated from diseased cotton roots
Rhizoctonia bataticola (Taub.) Butler	Isolated from diseased cotton roots
Trichoderma lignorum (Tode) Harz.	Centraalbureau Voor Schimmelcultures, Baarn, Holland
Aspergillus niger Van Tieghem	Centraalbureau Voor Schimmelcultures, Baarn, Holland

Media employed

1. Richards' agar
2. Cotton-root synthetic agar [Vasudeva, 1936]
3. Soil extract agar

Soil	100 gm.
Agar	20 gm.
Distilled water	1,000 c. c.

4. Soil-farmyard manure extract agar

Soil	50 gm.
Farmyard manure	50 gm.
Agar	20 gm.
Distilled water	1,000 c. c.

5. Glucose-peptone agar

Glucose	10 gm.
Peptone	2 gm.
KH_2PO_4	1 gm.
$MgSO_4$	0·5 gm.
Agar	15 gm.
Distilled water	1,000 c. c.

To start with, the purity of the fungi was ensured by taking a single hyphal tip.

B. Effect of mixture of organisms on growth

This effect was studied in thickly poured petri dishes containing about 50 c. c. of the medium. Altogether four media were used, i.e. cotton-root synthetic agar, Richards' agar, soil extract agar and soil-farmyard manure extract agar.

The general plan of the experiment was to place almost uniform inocula in the following manner in the centre of each plate and measure the rate of growth from day to day.

1. *R. solani* alone
2. *R. bataticola* alone
3. *Trichoderma lignorum* alone
4. *R. solani* and *Trichoderma* mixed
5. *R. bataticola* and *Trichoderma* mixed.

In the presence of *T. lignorum* in the mixed inocula the growth of *R. solani* and *R. bataticola* is appreciably reduced on all the media tested. In such cases the colonies which grew out consisted mainly of *T. lignorum*.

Effect of mixed inocula was also studied by inoculating the petri dishes containing Richards' agar at the centre with a suspension of hyphae of *R. solani* and *R. bataticola*. The inoculum was encircled at a distance of about 1 cm. by a suspension of spores of *T. lignorum* . It was observed that the small colony of *R. solani* and *R. bataticola* was completely encircled by *T. lignorum* and it was very rare that hyphae of these fungi penetrated through the barrier formed by *T. lignorum*.

In another set of experiments the fungi were grown in petri dishes containing Richards' agar. The depth of the medium in these petri dishes was about 1 cm. The two fungi *R. solani* or *R. bataticola* and *T. lignorum* were inoculated on opposite sides of the same petri dish. After about three days' growth the advancing hyphae of the two fungi met in the centre of the plate. The line of contact was clearly demarcated and was light brown in colour, turning dark brown with age. Inocula were taken from different positions in the colony so as to determine the distribution of the two fungi in the colony. Considering the line of demarcation as the central radial line, the inocula

were taken from this line as well as six lines running parallel to this at a distance of $\frac{1}{4}$, $\frac{1}{2}$ and 1 cm. on either side of the central line as shown in Fig. 1.

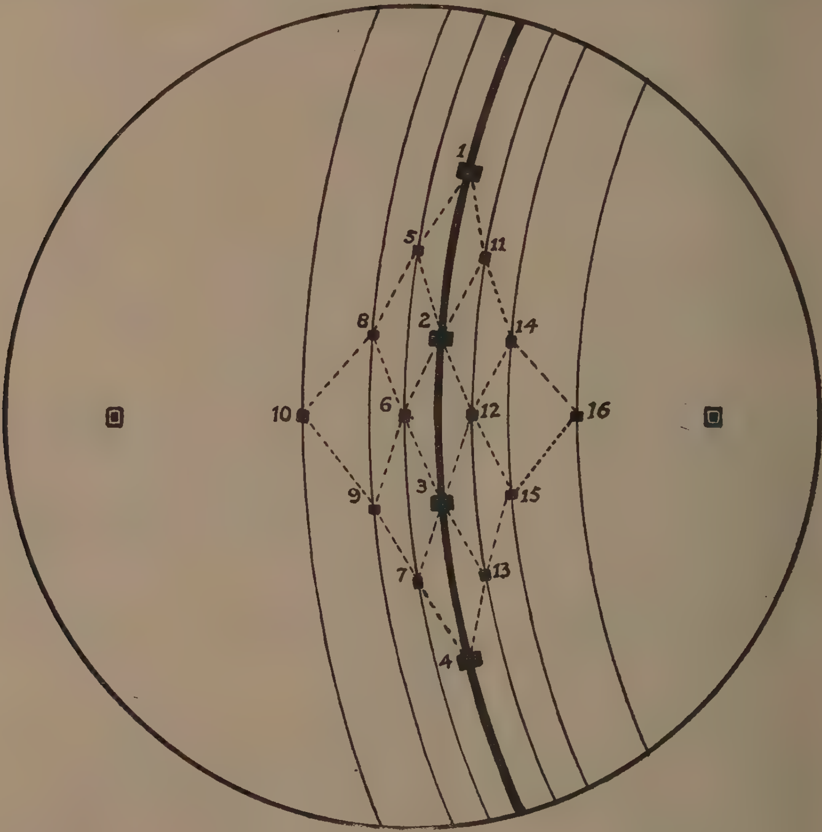


Fig. 1. Showing position of inocula

It might be mentioned that the rate of growth of *R. solani* and *R. bataticola* was retarded when the mycelium of *T. lignorum* approached close to it. *T. lignorum* continued to grow so as to cover the entire plate. After several days' further growth the brown line of contact could not be seen from the upper surface, but it was very clear from the lower surface.

Altogether 32 inocula were taken from each plate, i.e. 16 from upper surface and 16 from the corresponding positions from the lower surface after aseptically inverting the medium. The inocula were taken after 10, 18, 40 and 60 days' growth in triplicates. The results of a typical experiment are summarized in Table I.

The results show that the number of mixed inocula is greatest after 10 days' growth but diminishes as the growth progresses, whereas the frequency of occurrence of *T. lignorum* in almost a pure form increases.

TABLE I

Frequency of occurrence of R. Bataticola, R. Solani *and* T. lignorum *in mixed cultures*

Growth (days)	Surface of medium	*T. lignorum* and *R. bataticola*: Total inocula taken (3 plates)	Growth of mixed fungi, *R. bataticola* + *T. lignorum*	*R. bataticola*	*T. lignorum*	*T. lignorum* and *R. solani*: Total inocula taken (3 plates)	Growth of mixed fungi, *T. lignorum* + *R. solani*	*R. solani*	*T. lignorum*
10	Upper	48	18	8	22	48	14	3	31
	Lower	48	24	10	14	48	25	6	17
18	Upper	48	8	*Nil*	40	32*	3	*Nil*	29
	Lower	48	3	Do.	45	32*	2	Do.	30
40	Upper	48	7	Do.	41	48	8	Do.	40
	Lower	48	1	Do.	47	48	6	Do.	42
60	Upper	48	3	Do.	45	48	5	Do.	43
	Lower	48	2	Do.	46	48	4	Do.	44

* 2 plates only taken

After 10 days' growth 18·7 per cent inocula gave *R. bataticola* and 9·3 per cent gave *R. solani*, whereas after 18, 40 and 60 days ' growth none of the inocula yielded either *R. bataticola* or *R. solani*.

The results hold good both for upper and lower surface cultures. These cultural experiments clearly indicate that *T. lignorum* is antagonistic to the two *Rhizoctonias*. Such antagonistic effect in mixed cultures has been shown by Vasudeva [1930] for *Botrytis allii* and *Monilia fructigena*.

Another experiment was conducted in uniform Erlenmeyer flasks of 250 c. c. capacity containing 75 c. c. of Richards' solution. The fungi under study were inoculated singly and in mixtures in order to determine whether *T. lignorum* and *Aspergillus niger* would dominate the two *Rhizoctonias*. In this connection dry weights of the fungal mats of the cultures grown singly and in mixtures were taken after 15, 28, 48 and 60 days' growth. The colour and smell of the stales were noted. Observations were also made regarding the predominance of fungi in mixed cultures. The *p*H of the media was estimated before and after the growth of the fungi. The data of this experiment are summarized in Table II.

The data bring out the following points of interest :—

1. Mixed fungal mats of *T. lignorum* and *R. bataticola* are less in weight than *R. bataticola* alone throughout, i.e. after 15, 28, 46 and 60 days' growth.

2. Mixed fungal mats of *T. lignorum* and *R. solani* are less in weight than *R. solani* alone.

3. Mixed fungal mats of *A. niger* and *R. bataticola* are less in weight than *R. bataticola* alone excepting after 60 days' growth, where the growth in the mixed cultures is greater than *R. bataticola* alone. This may be explained on the basis of reduced growth after 60 days in the case of *R. bataticola*, which had fallen from 1·3 to 0·8 gm.

TABLE II

Growth of R. bataticola *and* R. solani *in liquid cultures in the presence of* T. lignorum *and* A. niger

Growth (days)	Pure: Fungus	Pure: Weight of mycelium (gm.)	Pure: Stale pH	Pure: Stale Colour	Mixed: Fungus	Mixed: Weight of mycelium (gm.)	Mixed: Stale Fungus predominant	Mixed: Stale pH	Mixed: Stale Colour	pH of control
15	*T. lignorum*	0·145	5·7	Light orange	*T. lignorum + R. bataticola*	0·206	*T. lignorum*	5·8	Light orange	4·5
	R. bataticola	0·777	5·2	Light yellow	*T. lignorum + R. solani*	0·112	Do.	5·2	Light yellow	
	R. solani	0·152	5·8	Turbid light yellow	*A. niger + R. bataticola*	0·631	*A. niger*	2·3	Light lemon	
	A. niger	0·795	2·8	Lemon	*A. niger + R. solani*	0·792	Do.	2·5	Do.	
					R. bataticola + R. solani	0·669	*R. bataticola*	5·0	Dirty yellow	
28	*T. lignorum*	0·289	6·0	Deep orange	*T. lignorum + R. bataticola*	0·205	*T. lignorum*	6·0	Orange	4·5
	R. bataticola	1·039	4·5	Light yellow	*T. lignorum + R. solani*	0·117	Do.	5·7	Light orange	
	R. solani	0·495	5·6	Turbid light yellow	*A. niger + R. bataticola*	0·918	*A. niger*	3·0	Lemon	
	A. niger	0·959	4·4	Lemon	*A. niger + R. solani*	0·788	Do.	3·0	Do.	
					R. bataticola + R. solani	1·196	*R. solani* and *R. bataticola*	6·2	Dirty yellow	
46	*T. lignorum*	0·336	6·0	Light salmon	*T. lignorum + R. bataticola*	0·284	*T. lignorum*	6·0	Light salmon orange	4·5
	R. bataticola	1·031	6·0	Ivory yellow	*T. lignorum + R. solani*	0·350	Do.	6·2	Do.	
	R solan	0·520	5·5	Honey yellow	*A. niger + R. bataticola*	0·970	*A. niger*	3·8	Primorse yellow	
	A. niger	0·908	4·5	Primorse yellow	*A. niger + R. solani*	0·926	Do.	3·6	Do.	
					R. bataticola + R. solani	0·893	*R. bataticola*	6·4	Pale pinkish buff	
60	*T. ligno um*	0·383	6·8	Salmon orange	*T. lignorum + R. bataticola*	0·352	*T. lignorum*	6·4	Bitter sweet orange	4·5
	R. bataticola	0·765	7·0	Crimson buff	*T. lignorum + R. solani*	0·356	Do.	6·4	Do.	
	R. solani	0·547	5·4	Ochraceous	*A. niger + R. bataticola*	0·973	*A. niger*	4·6	Primorse yellow	
	A. niger	0·910	4·7	Primorse yellow	*A. niger + R. solani*	0·859	Do.	4·6	Do.	
					R. bataticola + R. solani	0·857	*R. bataticola*	7·0	Pinkish buff	

4. Mixed fungal mats of *A. niger* and *R. solani* are throughout greater in weight than *R. solani* alone, but it may be mentioned that *A. niger* was greatly in predominance in all the cultures and no traces of *R. solani* were visible even after 15 days' growth.

5. Mixed fungal mats of *R. solani* + *R. bataticola* are greater in weight than *R. solani* alone throughout.

From the data it is clear that the growth of *R. bataticola* and *R. solani* is appreciably reduced in liquid cultures in the presence of *T. lignorum* and *A. niger*.

The *p*H of the stales from *T. lignorum*, *R. solani*, *R. bataticola* and their mixtures show that all these fungi tend to reduce the acidity of the medium.

Basal medium in the case of *A. niger* after 15 days' growth had become more acidic but after 28, 46 and 60 days' growth the *p*H of the filtrates again almost fell in line with the controls, i.e. a reduction in acidity. In the case of mixed cultures an increase in acidity occurred after 15, 28 and 46 days' growth, whereas after 60 days' growth the *p*H of the filtrates fell in line with the controls.

It might, however, be mentioned that *R. solani* and *R. bataticola* have a fairly wide range of toleration to acidity and alkalinity and show good growth between *p*H 4·0 and 8·6. Beyond these limits there is a fall in growth. *T. lignorum* and *A. niger*, show good growth between *p*H 2·8 and 8·2 with optimum growth between 4·0 and 5·0 but beyond 8·2 there is a rapid fall in growth.

This was tested on glucose-peptone agar in petri dishes. The *p*H of the medium was adjusted by the addition of malic acid and sodium bicarbonate. A range from 2·8 to 9·6 was set up.

C. Antagonistic effect of hyphae of T. lignorum *and* A. niger

It has been demonstrated that *T. lignorum* has a markedly depressing effect on *R. solani* and *R. bataticola* and that a brown line of demarcation appears at the junction of the hyphae of the two fungi when they are grown opposite to each other in the same plate.

The interaction of the hyphae of the two fungi, i.e. *T. lignorum* and *R. bataticola* or *R. solani* was studied in petri dishes containing Richards' agar.

A simple method of demonstrating their interaction was to pour the medium in such a way that the medium grades from very deep to very shallow from side to the centre of the plate. A similarly graded medium was also poured on the opposite side of the dish after the first one had set. A narrow channel was formed in the centre of the plate where the two slants met. This central line had either a very thin layer of medium, or the medium was almost absent. The two fungi were inoculated in the centre of the slants almost equidistant from the central line. Usually on the third day the hyphae of the fungi came in close proximity when a thorough microscopic examination was conducted. Such examination was continued at frequent intervals daily for several days. Study of the interaction of the fungi was also conducted on very thinly poured plates. About 7 c. c. of very hot medium was poured in the plate and vigorously shaken so as to spread the medium uniformly in

an extremely thin layer. Interaction of hyphae of *R. bataticola* with hyphae of *T. lignorum* and *A. niger* was studied in detail.

Plate XIX, figs. 1-4 show various stages of interaction of *T. lignorum* and *R. bataticola* hyphae.

It was observed that the hyphae of *T. lignorum* coil round hyphae of *R. bataticola*. Later the protoplasmic contents of the attacked hyphae of *R. bataticola* coagulate, the host hyphae dissolve and a substance of granular nature is given out.

Interaction of T. *lignorum* and *R. solani* was also studied microscopically and a similar coiling round of the hyphae and dissolution of the host hyphae was observed.

Plate XX, figs. 1-5 show interaction of *A. niger* and *R. bataticola*. In this case also coiling round of hyphae of *R. bataticola* by *A. niger* was observed. The protoplasmic contents of the attacked hyphae were seen to coagulate. The attacked hyphae later on give out a granular substance, shrink, turn pale and the cell walls and cross walls disappear.

Finally a thick, deep yellow substance was observed, which seemed to break up into numerous crystal-like bodies. It is not yet clear as to how the yellowish substance is formed. These results are in accordance with the findings of Weindeling [1932] and Porter [1924] who record that in mixed culture the hyphae of one fungus may show a dissolving effect upon the hypae of the other.

(*a*) *Toxic effect of filtrates*

After having studied the effect of *T. lignorum* when grown in close proximity to *R. solani* and *R. bataticola* it was considered interesting to study the effect of the filtrates of *T. lignorum* on the growth of *R. solani* and *R. bataticola*. For this purpose *T. lignorum* was grown in Erlenmeyer flasks of 300 c. c. capacity containing 100 c. c. of Richards' solution. The growth was allowed to proceed for 60 days at 30°C. At an interval of 10 days three flasks were taken and their contents filtered through Buchner filter and centrifuged in order to remove the remaining spores and mycelium. Before using the filtrate it was ensured by miscroscopic examination that the filtrate had almost entirely been freed of the fungus. Dry weights of the fungus were taken along with the *p*H of the stale as well as of controls. All this process was carried out aseptically in sterilized apparatus in order to reduce the possibility of contamination to the minimum. The filtrate was divided into 5-c. c. lots in uniform test-tubes and these inoculated in triplicates with *T. lignorum*, *R. solani* and *R. bataticola*. Control test-tubes containing Richards' solution were also similarly inoculated.

All these cultures in test-tubes were examined for growth after six days.

Ten and 20 days' stale of *T. lignorum* did not have any marked effect on its own growth or on the growth of *R. solani* and *R. bataticola*. Depression in growth was, however, observed in 30 days' stales in the case of all the three fungi. In 40, 50 and 60 days' stales *R. solani*, *R. bataticola* and *T. lignorum* respectively failed to grow, whereas 10 days previous to failure in growth a marked reduction was noticed in the case of each fungus.

It was further shown that the toxic principle in 60-66 days' old stale is not thermostable and could be easily removed by heating. It could also be removed by dilution.

FIG. 1. (A) Hyphæ of *T. lignorum* and (B) Hyphæ of *R. bataticola*, in close proximity (×416)

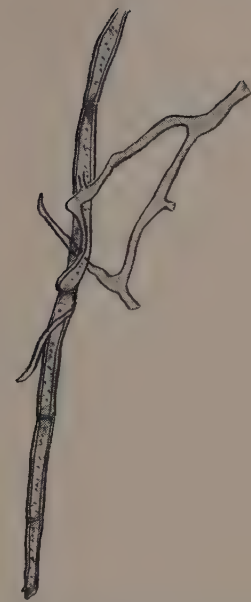
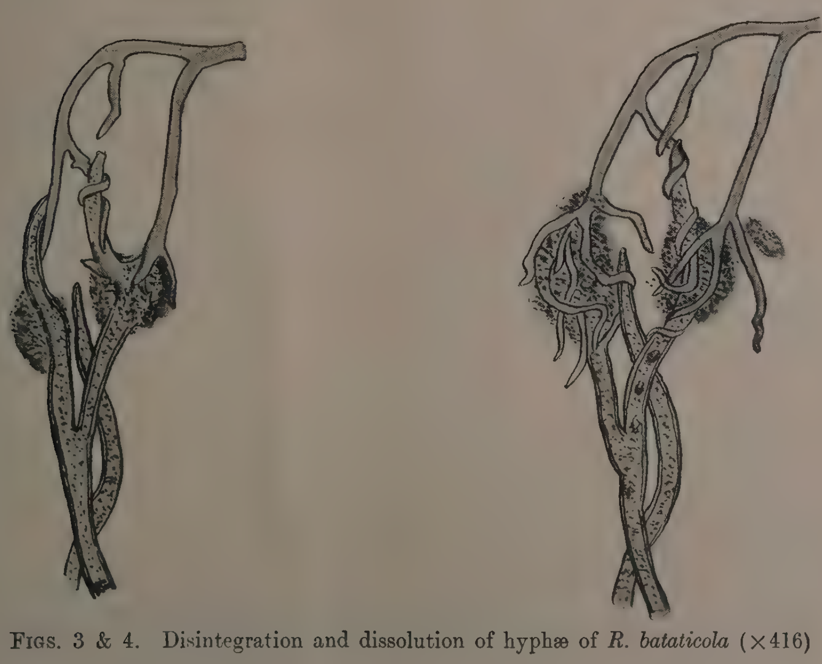


FIG. 2. Coiling round of hyphæ of *R. bataticola* by *T. lignorum* (×416)



FIGS. 3 & 4. Disintegration and dissolution of hyphæ of *R. bataticola* (×416)

[*Ind. J. Agric. Sci.*, Vol. 11, Part III

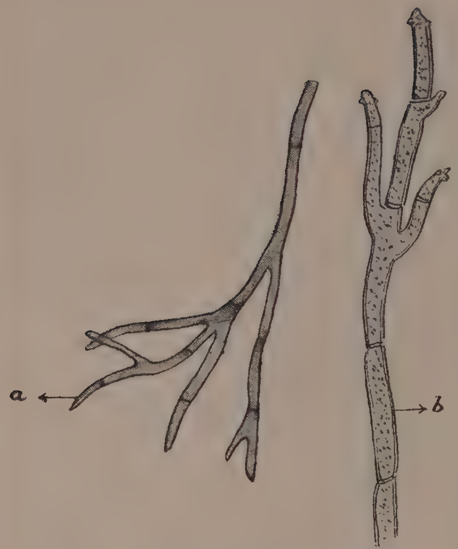


FIG. 1. Hyphæ of (*a*) A. niger, (*b*) *R. bataticola* (×416)

FIG. 2. Coiling of hyphæ of *A. niger* round *R. bataticola* hyphæ (×416)

FIGS. 3, 4 & 5. Shrinkage and dissolution of *R. bataticola* hyphæ and liberation of granular substance (×416)

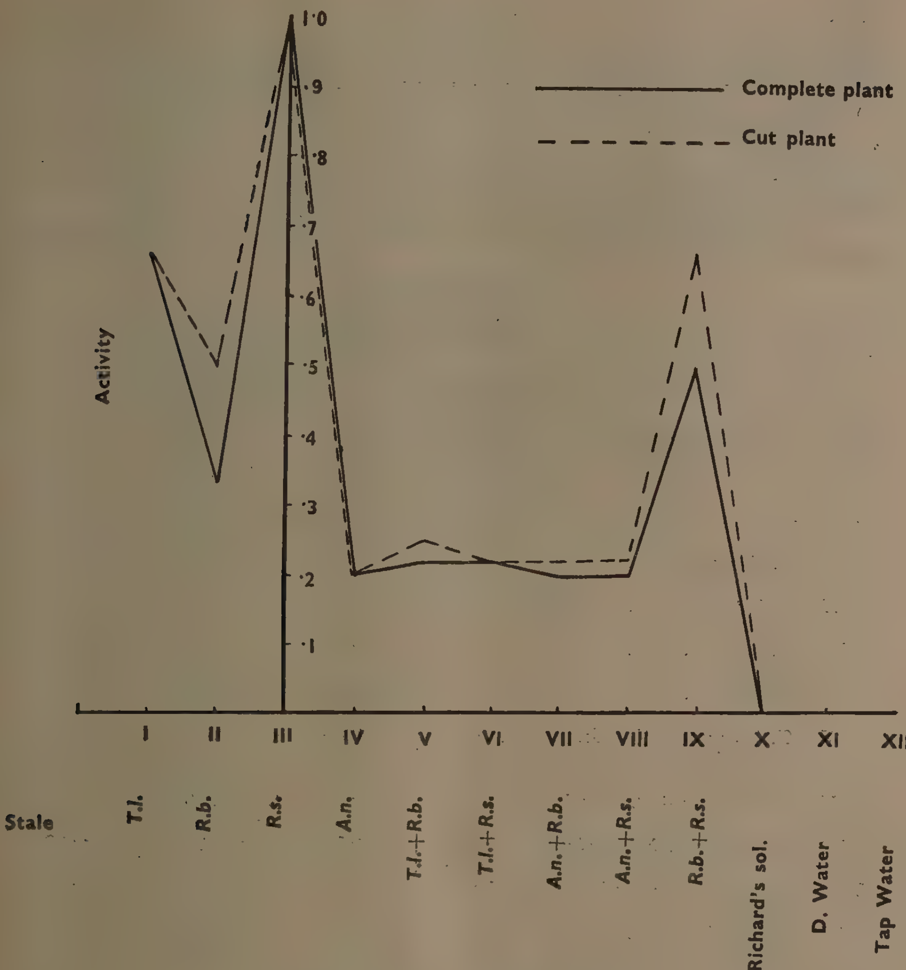


FIG. 2. Activity of various filtrates

(*b*) *Activity of filtrates*

The toxic effect of stale of various fungi when grown singly and in mixtures was studied on young cotton plants 15 days old and of variety Mollisoni 39 (*G. indicum*). The plants were removed from the soil by washing their roots so as to avoid injury to the roots and washed thoroughly in running tap water and then in sterilized distilled water. These plants were transferred to uniform specimen tubes containing 35 c. c. of 60 days old stale of various fungi. The plants were maintained in erect positions in the specimen tubes by passing

them through split corks. Every effort was made to maintain aseptic conditions. Control plants were kept in Richards' solution, tap water and distilled water. The test was conducted in triplicates both for plants with roots and for plants without root-system which had been aseptically removed.

Observations regarding condition of the plants were made after every 30 minutes.

The activity of the filtrates is inversely proportional to the time required to bring about wilting of the plants.

The results of this experiment are summed up in Table III. Fig. 2 shows the activity of various filtrates.

TABLE III

Activity of filtrates

Lot No.	Stale of fungus (60 days old)	Time for wilting of complete plants (minutes)	Activity	Time for wilting of plants without roots (minutes)	Activity
I	*T. lignorum* . .	90	0·66	90	0·66
II	*R. bataticola* . .	180	0·33	120	0·50
III	*R. solani* . . .	60	1·00	60	1·00
IV	*A. niger* . . .	300	0·20	300	0·20
V	*T. lignorum* + *R. bataticola*	270	0·22	240	0·25
VI	*T. lignorum* + *R. solani*	270	0·22	270	0·22
VII	*A. niger* + *R. bataticola*	300	0·20	270	0·22
VIII	*A. niger* + *R. solani* .	300	0·20	270	0·22
IX	*R. bataticola* + *R. solani*	120	0·50	90	0·66
X	Control Richards' solution	..	0·00	..	0·00
XI	Distilled water . .	..	0·00	..	0·00
XII	Tap water. . .	..	0·00	..	0·00

The results show that the activity of filtrates of *R. solani* and *R. bataticola* is reduced when these fungi are grown in mixtures with *T. lignorum* and *A. niger*. The results are in accordance with the findings of Vasudeva [1935] for the filtrates of mixed cultures of *Botrytis cinerea*. Such reduction in activity could probably be ascribed to the staling phenomenon or to the parasitic action of *T. lignorum* and *A. niger* or both.

Summary

1. The presence of *Trichoderma lignorum* and *Aspergillus inger* in the inoculum of *Rhizoctonia bataticola* and *R. solani* greatly interferes with the growth of the latter fungi.

2. The hyphae of *Trichoderma lignorum* and *Aspergillus niger* show a dissolving effect on the hyphae of *Rhizoctonia bataticola* and *R. solani*.

3. The activity of filtrates of *Rhizoctonia bataticola* and *R. solani* is reduced when these fungi are grown mixed with *Trichoderma lignorum* and *Aspergillus niger*.

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SOME BREEDING INVESTIGATIONS ON LINSEED (*LINUM USITATISSIMUM* L.) IN THE PUNJAB

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LINSEED is an important crop in certain parts of the Punjab, occupying an area of about 32,000 acres annually. It is grown chiefly in the districts of Kangra, Gurdaspur, Hoshiarpur and Sialkot, where it constitutes about 75 per cent of its total area in the province. The crop is generally sown in October-November and is harvested in April, being grown entirely for the oil in its seed.

In view of the importance of linseed as an oilseed crop in the Punjab, its botanical study was started at Lyallpur during 1932. An examination then made of the linseed crop grown by the farmers in different parts of the province revealed it to be an admixture of several types which have been classified into 33 distinct unit species on the basis of differences in the morphological characters of the plants. A few types selected from amongst these unit species have already proved to be superior to the local mixed strains both in yield and oil content of seeds, and are, therefore, likely to replace, in due course, the mixed strains already under cultivation in the province. It may, however, be noted that none of the Punjab types happens to possess yellow or fawn colour of seeds and, since these colours are considered to be correlated with greater quantity and better quality of oil and are therefore liked in trade, hybridization between high-yielding, brown-seeded Punjab types and yellow- and fawn-seeded Pusa hybrids, which as such have not given satisfactory results in the Punjab, was resorted to. The study of these crosses permitted observations being made on the mode of inheritance of several morphological characters, and the purpose of the present paper is to record data so far collected and the results obtained.

Material and methods

For the purpose of these studies reciprocal crosses were made between four promising Punjab types and two Pusa hybrids. The detailed morphological characters of the parental types employed are as follows :

Name of parent	Habit of growth	Opening of flowers	Colour of					
			Petals	Filaments	Anthers	Style	Stigma	Seed
Pusa LH 10 .	Erect and open	Complete .	White	Blue	Yellow	Blue	Blue with purple shade	Yellow
Pusa LH 21 .	Erect and open	Complete .	Blue	Blue	Blue	Blue	Blue	Fawn
Punjab T 4 .	Spreading and open	Partial .	White	White	Yellow	White	White .	Reddish brown
Punjab T 5 .	Spreading and open	Partial . .	White	White	Yellow	White	White .	Reddish brown
Punjab T 22 .	Erect and open	Complete .	Blue	Blue	Blue	Blue	Blue .	Brown
Punjab T 23 .	Spreading and open	Complete .	Blue	Blue	Blue	Blue	Blue .	Brown

Crosses between the above-mentioned types and hybrids were made during 1935-36 and the F_1, F_2 and F_3 progenies were grown in the oilseeds experimental area at Lyallpur during subsequent years. For raising F_2 and F_3 only selfed seed obtained by bagging plants with fine muslin bags was used.

In the various crosses made, the inheritance of the following characters has been studied and an attempt has also been made for working out the linkage relationship of these characters.

1. Colour of petal
2. Shape of petal and opening habit of flowers
3. Colour of anthers
4. Colour of seed

Experimental results

1. *Inheritance of petal colour*

The detailed results of segregation obtained in the case of each of the four crosses studied are given below :

(*i*) *LH 10* × *T 22*.—LH 10 has white petals with faint violet veins at the base. The petals of T 22 are blue in colour. The F_1 had blue petals like T 22. The F_2 population showed the following phenotypes of petal colour and their frequencies.

	Segregation in F_2			Value of P
	Blue	White	Total	
1937-38—				
Observed	142	53	195	0·50
Expected on 3 : 1 ratio . . .	146·25	48·75	195	
1938-39—				
Observed	264	74	338	0·20
Expected on 3 : 1 ratio . . .	253·5	84·5	338	

In F_3 the following segregations were observed during 1938-39 :—

Number of cultures and nature of parent plants	Segregation	Frequencies	
		Observed	Expected
15 cultures from plants with blue petals like T 22	Pure blue like T 22	6	5·0
	3 blue : 1 white .	9	10·0
15 cultures from plants with white petals like LH 10	Pure white . .	15	15

(*ii*) *LH 10* × *T 23*.—LH 10 has white petals with faint violet veins a the base. The petals of T 23 are blue. The F_1 had blue petals like T 23 The following phenotypes of petal colour and their frequencies were observed in F_2 :—

	Segregation in F_2			Value of *P*
	Blue	White	Total	
1937-38—				
Observed	1,504	526	2,030	0·36
Expected on 3 : 1 ratio . . .	1,522·5	507·5	2,030	
1939-40—				
Observed	911	314	1,225	0.62
Expected on 3 : 1 ratio . . .	918·75	306·25	1,225	

In F_3 the following segregations were observed in the year 1939-40 :—

Number of cultures and nature of parent plants	Segregation	Frequencies	
		Observed	Expected
52 cultures from plants with blue petals like T 23	Pure blue . .	16	17·3
	3 blue : 1 white .	36	34·6
113 cultures from plants with white petals like LH 10	Pure white . .	113.	113

(*iii*) *LH 21 × T 4.*—LH 21 has blue petals and T 4 has white ones. The F_1 had blue petals like LH 21. The F_2 population showed the following phenotypes of petal colour and their frequencies in the year 1938-39 :—

	Segregation in F_2			Value of P
	Blue	White	Total	
Observed	405	147	552	0·40
Expected on 3 : 1 ratio . . .	414	138	552	

In F_3 the following segregations were observed during 1939-40 :—

Number of cultures and nature of parent plants	Segregation	Frequencies	
		Observed	Expected
22 cultures blue flowered in F_2 . .	Pure blue . .	6	7·33
	3 blue : 1 white .	16	14·66
8 cultures white flowered in F_2 . .	Pure white . .	8	8

(*iv*) *LH 21 × T 5.*—The petals of LH 21 are blue in colour but those of T 5 are white. The F_1 had blue petals like LH 21. The F_2 progenies showed the following phenotypes of petal colour and their frequencies in the year 1938-39 :—

	Segregation in F_2			Value of P
	Blue	White	Total	
Observed	367	111	478	0·39
Expected on 3 : 1 ratio . . .	358·5	119·5	478	

In F_3 the following segregations were observed during 1939-40 :—

Number of cultures and nature of parent plants	Segregation	Frequencies	
		Observed	Expected
49 cultures blue flowered in F_2 . .	Pure blue . .	13	16·33
	3 blue : 1 white .	36	32·66
21 cultures white flowered in F_2 . .	Pure white . .	21	21

Segregation in F_2 and the behaviour of F_3 progenies in all the four crosses under study show clearly that there is a single-factor difference between the blue and white colours of petal.

2. Inheritance of the opening habit of flowers

Flowers of T 22, T 23, LH 10 and LH 21 have broad petals and open completely, but the flowers of T 4 and T 5 have 'crimped' petals and open partially. Observations with regard to the opening habit of the flowers were made in the crosses LH 21 × T 4 and LH 21 × T 5. The flowers of F_1 were broad petalled and opened completely. In F_2 and F_3 progenies all the flowers with blue petals had broad petals and opened completely, while all the white flowers were 'crimped' and opened partially, showing a complete linkage between petal colour and the opening habit of the flowers. Like petal colour, therefore, there is only a monogenic difference between the broad and 'crimped' petal characters.

3. Inheritance of anther colour

All the plants of the three parents with blue petals had blue colour of anthers, while all the three parents having white petal colour had yellow anthers. The anther colour in the case of all the F_1 plants was blue. In F_2 and F_3 progenies the anther colour was found to be completely associated with the petal colour ; all the plants with the blue flowers had blue colour of anthers, while those with white petal colour had yellow anthers, showing a complete linkage between the characters concerned and also a monogenic difference between blue and yellow anther colours.

4. Inheritance of seed colour

The results of seed colour inheritance obtained in the case of different crosses are described below :—

(*i*) *LH 10 × T 22.*—LH 10 has bold yellow seeds, while T 22 has bold brown seeds. The F_1 progenies had bold brown seeds. The following were the observed phenotypes for seed colour and their frequencies in F_2 :—

	Segregation in F_2					Value of of P
	Brown	Grey	Fawn	Yellow	Total	
1937-38—						
Obrserved . . .	117	39	33	6	195	0·25
Expected on 9 : 3 : 3 : 1 ratio	109·69	36·56	36·56	12·19	195	
1938-39—						
Observed . . .	203	55	60	20	338	0·53
Expected on 9 : 3 : 3 : 1 ratio	190·125	63·375	63·375	21·125	338	

In F_3 the following segregations were observed during 1939-40 :—

Number of cultures and nature of parent plants	Segregation	Frequencies	
		Observed	Expected
14 cultures brown seeded in F_2 . . .	Pure brown . .	2	1·55
	Like F_2 . .	8	6·22
	3 brown : 1 grey .	2	3·11
	3 brown : 1 fawn .	2	3·11
30 cultures grey seeded in F_2 . .	Pure grey . .	11	10
	3 grey : 1 yellow .	19	20
17 cultures fawn seeded in F_2 . .	Pure fawn . .	12	5·66
	3 fawn : 1 yellow .	5	11·33
14 cultures yellow seeded in F_2 . .	Pure yellow . .	14	14

(*ii*) *LH 10* × *T 23*.—LH 10 has yellow seeds and T 23 has brown seeds. The F_1 had brown seeds like T 23. In the F_2 progenies four different phenotypes of seed colour were observed with the following frequencies :—

	Segregation in F_2					Value of P
	Brown	Grey	Fawn	Yellow	Total	
1938-39—						
Observed . . .	1,137	392	379	122	2,030	0·90
Expected on 9 : 3 : 3 : 1	1,141·91	380·61	380·61	126·87	2,030	
1939-40—						
Observed . . .	645	220	207	61	3	0·61
Expected on 9 : 3 : 3 : 1	637·31	212·44	212·44	70·81	1,133	

In F_3 the following segregations were observed during 1939-40 :—

Number of cultures and nature of parent plants	Segregation	Frequencies	
		Observed	Expected
33 cultures brown seeded in F_2	Pure brown	4	3.66
	Like F_2	12	14·66
	3 brown : 1 grey	6	7·33
	3 brown : 1 fawn	11	7·33
17 cultures grey seeded in F_2	Pure grey	5	5·66
	3 grey : 1 yellow	12	11·32
10 cultures fawn seeded in F_2	Pure fawn	3	3·33
	3 fawn : 1 yellow	7	6·66
28 cultures yellow seeded in F_2	Pure yellow	28	28

(*iii*) *LH 21 × T 4.*—LH 21 has got fawn colour of seeds while the seeds of T 4 are reddish brown in colour. The seeds of the F_1 progenies were reddish brown in colour like T 4. In F_2 the following segregation for seed colour was observed in the year 1938-39 :—

	Segregation in F_2			Value of *P*
	Reddish brown	Fawn	Total	
Observed	415·0	137·0	552	0·92
Expected on 3 : 1 ratio	414·0	138·0	552	

In F_3 the following segregations were observed during 1939-40 :—

Number of cultures and nature of parent plants	Segregation	Frequencies	
		Observed	Expected
14 cultures brown seeded in F_2	Pure brown	5	4·66
	3 brown : 1 fawn	9	9·33
16 cultures fawn seeded in F_2	Pure fawn	16	16

(*iv*) *LH 21* × *T 5*.—LH 21 has got fawn colour of seeds, while the seeds of T5 are reddish brown. All the plants in the F_1 progenies had brown seeds and in F_2 the following segregation was observed for the seed colour during 1938-39 :—

	Segregation in F_2			Value of P
	Reddish brown	Fawn	Total	
Observed	320·0	108·0	428	0·74
Expected on 3 : 1 ratio . . .	321·0	107·0	428	

In F_3 the following segregations were observed during 1939-40 :—

Number of cultures and the nature of parent plants	Segregation	Frequencies	
		Observed	Expected
17 cultures brown seeded in F_2 . .	Pure brown . .	6	5·66
	3 brown : 1 fawn .	11	11·34
53 cultures fawn seeded in F_2 . .	Pure fawn . .	53	53

The above results show that two factors are responsible for the brown colour of seed. In the case of crosses between the brown- and yellow-seeded types four different phenotypes, viz. brown, grey, fawn and yellow, appear in the ratio of 9 : 3 : 3 : 1 in F_2. Similar results have been recorded by Tammes [1928] and Shaw *et al.* [1931]. Fawn colour of seed has behaved as a simple recessive to brown colour, proving a monogenic difference between the two colours.

It is of special interest to note that as a result of these studies a large number of pure-breeding yellow- and fawn-seeded hybrids having desirable combination of other characters have now become available. These are being tried with a view to selecting the best of these for general cultivation.

5. Linkage between flower and seed colours

It has been shown above that there is a single-factor difference between blue and white flower colours, while brown seed colour is controlled by two factors. It will be interesting to find out the relationship of the genes responsible for the seed and flower colours respectively when the segregation of both the characters is considered together. In the case of independent assortment of the genes responsible for the flower and seed colours a tri-hybrid ratio, viz. 27 : 9 : 9 : 9 : 3 : 3 : 3 : 1 should be expected. The observed and expected frequencies of the various phenotypic classes obtained for each

of the two crosses studied when the segregation of flower and seed colour is considered together are given in Table I.

TABLE I

Observed and expected frequencies of various phenotypic classes

Cross	Phenotypes / Flower colour / Seed colour	GMD blue brown	GMd white brown	GmD blue grey	gMD blue fawn	Gmd white grey	gMd white fawn	gmD blue yellow	gmd white yellow	Total
LH 10 × T 22	Observed .	216	14	7	66	68	8	2	11	392
	Expected .	165·38	55·12	55·12	55·12	18·38	18·38	18·38	6·12	392
	$\frac{(O-E)^2}{E}$	15·49	30·68	42·01	2·14	134·02	5·85	14·59	3·88	245·7
LH 10 × T 23	Observed .	629	16	31	192	189	15	6	55	1,133
	Expected .	477·98	159·33	159·33	159·33	53·11	53·11	53·11	17·70	1,133
	$\frac{(O-E)^2}{E}$	47·71	12·89	103·36	6·70	347·69	27·35	41·79	81·84	669·33

It will be observed from Table I that the frequency of certain phenotypic classes has considerably fallen short of the expectation, while the frequency of certain other classes is far in excess of the values expected according to the trihybrid ratio referred to above. The value of χ^2 which is very high in both the crosses also shows that the fit of the observed and expected values is by no means good. Such large deviation would obviously lead to the conclusion that the genes responsible for seed and flower colours are not inherited independently of each other.

With a view to finding out the exact linkage relationship of the gene **D** responsible for the appearance of blue colour in the flowers with each of the genes **G** and **M** both of which together produce the brown colour of seed as discussed later on, the F_2 data given in Table I were analysed in details. The results obtained are described below :—

(*a*) *Linkage of flower-colour factor **D** with seed-colour factor **M**.*—The observed and expected frequencies of the four phenotypic classes when both these factors are considered together are given in Table II from which it will be observed that the frequencies of the double dominant and double recessive classes in both the crosses are far in excess of the expected values, while the frequencies of the middle classes fall short of the expectation.

The value of χ^2 is extremely high in both the crosses. This clearly shows that flower factor **D** and seed-colour factor **M** are not inherited independently. Evidently, therefore, these two factors are linked together.

The theoretical frequencies of the various phenotypes have been calculated according to the product-ratio method of Fisher. This method has been found to be the most efficient by Alam [1929] who has recommended this for general use. The results are given in Table III.

TABLE II

Observed and expected frequencies of the four phenotypic classes in crosses LH 10 × T 22 and LH 10 × T 23

Cross	Phenotypes / Flower colour / Seed colour	MD blue brown and fawn	Md white brown and fawn	mD blue grey and yellow	md white grey and yellow	Total
LH 10×T 22 .	Observed . .	282	22	9	79	392
	Expected on 9 : 3 : 3 : 1 ratio	220·5	73·5	73·5	24·5	392
	$\frac{(O-E)^2}{E}$	16·05	36·08	56·60	123·76	232·49
LH 10×T 23 .	Observed . .	821	31	37	244	1,133
	Expected on 9 : 3 : 3 : 1 ratio	637·31	212·44	212·44	70·81	1,133
	$\frac{(O-E)^2}{E}$	52·94	154·96	144·88	423·59	776·37

TABLE III

Theoretical frequencies calculated according to Fisher's product-ratio method

Cross	Phenotypes / Flower colour / Seed colour	MD blue brown and fawn	Md white brown and fawn	mD blue grey and yellow	md white grey and yellow	Total	Value of P^2	Cross-over per-centage
LH 10 × T 22	Observed .	282·00	22·00	9·00	79·00	392	0·8529	7·65
	Calculated.	279·59	14·41	14·41	83·59	392		
	$\frac{(O-C)^2}{C}$	0·02	3·99	2·03	0·25	6·29		
LH 10 × T 23	Observed .	821·00	31·00	37·00	244·00	1,133	0·8795	6·72
	Calculated.	815·62	34·00	34·00	249·12	1,133		
	$\frac{(O-C)^2}{C}$	0·03	0·26	0·26	0·10	0·65		

The above results show that the flower-colour factor **D** is partially linked with the seed-colour factor **M**, the two having a cross-over value of nearly 7 per cent.

(*b*) *Linkage of flower-colour factor* **D** *with seed-colour factor* **G**.—The observed and theoretical frequencies of the various phenotypic classes when both these factors are considered together are given in Table IV. It is assumed that both these factors are inherited independently of each other.

TABLE IV

Observed and theoretical frequencies of the various phenotypic classes in crosses LH 10 × T 22 and LH 10 × T 23

Cross	Frequencies of various pehnotypes					Total
	Phenotypes	**GD**	**Gd**	**gD**	**gd**	
	Flower colour	blue	white	blue	white	
	Seed colour	brown and grey	brown and grey	fawn and yellow	fawn and yellow	
LH 10 × T 22	Observed . .	223·00	82·00	68·00	19·00	392·00
	Expected on 9 : 3 : 3 : 1 ratio	220·50	73·50	73·50	34·50	392·00
	$\frac{(O-E)^2}{E}$	0·03	0·99	0·41	1·23	2·66
LH10 × T23	Observed . .	660·00	205·00	198·00	70·00	1,133·00
	Expected on 9 : 3 : 3 : 1 ratio	637·31	212·46	212·46	70·81	1,133·00
	$\frac{(O-E)^2}{E}$	0·81	0·26	0·98	0·01	2·06

In both of these crosses the value of χ^2 is very small and the values of *P* from Fisher's table are 0·45 and 0·56 for the crosses L H 10 × T 22 and L H 10 × T 23 respectively. This clearly shows that there is no linkage between the flower-colour factor **D** and seed-colour factor **G**.

Further support is lent to the above-mentioned conclusions from the study of the crosses LH 21 × T 4 and LH 21 × T 5. LH 21 has got blue petal colour and fawn seed colour. Types 4 and 5 have got white petal colour and brown seed colour. The observed and expected frequencies of the four phenotypic classes in each of these crosses are presented in Table V.

TABLE V

Observed and expected frequencies of the four phenotypic classes in crosses LH 21 × T 4 and LH 21 × T 5

Cross	Frequencies of various phenotypes					Total	Value of P
	Phenotypes	GD	Gd	gD	gd		
	Flower colour	blue	white	blue	white		
	Seed colour	brown	brown	fawn	fawn		
LH 21 × T 4	Observed	275·00	102·00	97·00	33·00	507	
	Expected on 9 : 3 : 3 : 1 ratio	285.19	95·06	95·06	31·69	507	0.69
	$\frac{(O-E)^2}{E}$	0.36	0·51	0·04	0·54	1·45	
LH 21 × T 5	Observed	255·00	72·00	85·00	23·00	435	
	Expected on 9 : 3 : 3 : 1 ratio	244·69	81·56	81·56	27·19	435	0·50
	$\frac{(O-E)^2}{E}$	0·43	1·12	0·15	0·64	2·34	

As is evident from the values of χ^2 and P given in the last two columns of Table V, the fit of the observed frequencies with those expected on dihybrid ratio of 9 : 3 : 3 : 1 is quite good. This again confirms the conclusions drawn from the study of the first two crosses that flower factor **D** has got no linkage with seed-colour factor **G**.

DISCUSSION OF RESULTS

Tammes [1928] has determined eight hereditary factors, **A**, **B**-1, **B**-2, **C**, **D**, **E**, **F** and **K**, which influence the colour and its distribution in the petals. According to her findings, three of the factors **B**-1, **B**-2 and **C** are basal factors necessary to produce colour in the petals. If any one of them is recessive, the petal colour becomes white. Factors **D** and **F** determine the tint of the petals which may be pink, lilac, etc. Factors **A** and **E** are colour intensifiers, **E** having a stronger effect than **A**. The factor **K** is responsible mainly for the distribution of colour on the petals, its presence making the petal uniformly coloured. In its absence the colour is mainly restricted to upper edge. Different combinations of these hereditary factors yield, besides white forms, 32 genotypically different coloured forms.

Shaw *et al.* [1931] have also investigated the inheritance of flower and seed colours in the varieties of Indian linseed in addition to studying the behaviour of style and stigma colours. These authors have postulated some important deviations in the action and interaction of the factors governing different characters. According to their view there are only seven factors, namely **B**, **C**, **D**, **E**, **F**, **K** and **N**, which control the flower colour. Three of these factors, viz. **C**, **D** and **E**, also control the shape of the petal, it being ' crimped ' when all of these factors are present. The anther colour depends upon the action of factor **H** with two other factors which determine petal colour. The basal colour of seed-coat is considered by these authors to be yellow which is transformed into fawn by the presence of two factors, **M** and **D**. In the presence of an additional factor **G** the fawn colour changes to brown. In absence of **D** and presence of **G** the seed-coat colour is grey irrespective of the presence or absence of **M**. The factor **X** intensifies the seed-coat colour.

It is of special interest to note that in the crosses studied by Shaw *et al.*, they found complete linkage of brown and fawn seeds with blue or lilac petals and of grey and yellow seeds with white and pink phenotypes. In contrast to this our results given above show conclusively that the complete linkage between flower colour and seed colour as borne out by Shaw's results is not valid, as is evident from the fact that phenotypes having combination of blue flower with grey seed and that of white flower with fawn seed appear in F_2 progenies of each of the crosses L H 10 × T 22 and L H 10×T 23. In the light of these results, therefore, the hypothesis postulated by Shaw *et al.* regarding the various factors controlling different seed colours requires to be modified. From our results it is logical to believe that only two factors, **G** and **M**, control the seed colour. When both these factors are absent, the seed colour is yellow. When only **M** is present, it changes the seed colour to fawn, while in presence of **G** alone the seed colour is grey. When both **M** and **G** are present together, the seed colour is brown. Our results further show that the seed-colour factor **M** is linked with flower factor **D** though not completely, the cross-over value between the two being nearly 7 per cent. The other seed factor, viz. **G**, is inherited independently of the flower-colour factor **D**.

From the results reported in this paper it is not possible to deduce any definite genetical formulæ for the constitution of the various parental types used in crossing, but the monofactorial segregation for flower colour and both mono and bifactorial segregations for seed colour as well as the complete linkage between petal colour and anther colour can be explained by assuming the following constitutions of the parental types concerned using the same letters to represent the various colour factors as suggested by Shaw [1931].

Types	Petal colour	Shape of petal	Anther colour	Seed colour	Constitution
LH 10 . . .	White	Flat	Yellow	Yellow	**BCdEFKNHmg**
LH 21 . . .	Blue	Flat	Blue	Fawn	**BCDEFKNHMg**
Punjab T 4 and T 5 .	White	Crimped	Yellow	Brown	**bCDEFKNHMG**
Punjab T 22 and T 23 .	Blue	Flat	Blue	Brown	**BCDEFKNHMG**

SUMMARY

(1) The results of studies on the inheritance of characters as obtained from the crosses made between a few Punjab types and Pusa hybrids have been described and as a result of these investigations, the following important conclusions can be drawn :

(*a*) Blue and white colours of petals behave as simple allelomorphs and segregate according to the monohybrid ratio of 3 : 1.

(*b*) The yellow colour of anthers was completely associated with the white colour and 'crimped' shape of petals. Similarly the blue colour of anthers was completely linked with the blue colour and flat shape of the petal in all the crosses studied.

(*c*) Two factors (**M** and **G**) are responsible for the brown colour of seed. In the case of crosses between the brown and yellow-seeded types, four different phenotypes, viz. brown, grey, fawn and yellow, have been found to appear in the ratio of 9 : 3 : 3 : 1 in the F_2 progenies.

(*d*) The fawn colour of seed behaves as simple recessive to brown.

(*e*) One of the two genes responsible for the production of brown colour of seeds was found to be linked with the gene producing blue colour in petals. The other gene of seed colour has got no association with the petal colour.

(2) A large number of new pure-breeding hybrids having combination of yellow and fawn colours of seed with other desirable characters have now become available.

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OBSERVATIONS ON *APHELINUS MALI* HALD. IN THE PUNJAB

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WOOLLY aphis (*Eriosoma lanigerum* Hausm.) was introduced into the Punjab in 1909. It is at present confined to the hilly tracts and is found in Bajaura, Bandrole, Dobi, Jubbal State, Kasauli, Koti State, Kulu, Manali, Naggar, Niramitii, Raison, Karjan, Katrain, Kotgarh, Kot Khai, Mashobra, Shirir, Simla and Solan [Rahman and Khan, 1941]. It is destroyed by serveral predators but none of them exercises an effective check over it. Insecticidal and other control methods tried against it, though successful, were found to be expensive. It was, therefore, decided to introduce *Aphelinus mali* Hald. for its control. The parasite was imported from the Franham House Laboratory, Franham Royal, Bucks, England, at the suggestion, and through the help, of the Imperial Council of Agricultural Research, New Delhi,* by M. Afzal Husain, the then Entomologist to Government, Punjab, Lyallpur. In the first consignment (despatched from England in June 1936 and received in Kulu in August 1936) all the parasites emerged and perished on the way. In August 1937, four consignments which were despatched and received in succession (by air mail) yielded living adult parasites. On their arrival at Kulu they were supplied with woolly aphis on infested twigs in a wire-gauze cage lined with voile cloth.† The first batch of adult parasites was liberated in a severely infested orchard of 40 trees at Raison on 5 September 1937. By 11 September 1937 they had parasitized 29 woolly aphis. Afterwards the parasite established and quickly

*The help of the Council and that of the authorities of the Franham House Laboratory is gratefully acknowledged.

†The parasite was established in the Kulu valley as follows :—

A wire-gauze (with 144 meshes per sq. inch) cage 10 ft. × 7 ft. × 7 ft. was put up in a heavily infested orchard prior to the arrival of the parasite from England. It was lined with voile cloth to safeguard against its early and premature escape. Apple twigs covered with woolly aphis were cut off the trees and planted in the cage. When the parasite had become sufficiently numerous, a hole of about 4 in. diameter was made in the cloth to allow it to escape.

distributed itself in many of the infested orchards of the Kulu valley. Information presented in this paper was acquired during the course of acclimatizing the parasite in the Punjab.

Alternative hosts

Elsewhere *A. mali* Hald. has been reported from about 22 different kinds of aphids [Greenslade, 1936]. In the Punjab we offered the following species of aphids to it but it did not parasitize any of them :—

(1) *Aphis laburni* Kalt., (2) *Rhopalosiphum* sp., (3) *Rhopalosiphum pseudobrassicae* Davis, (4) *Anuraphis* sp., (5) *Prociphilus oriens* Mordov., (6) *Pemphigella aedificator* Buckt., (7) *Eriosoma* sp. (on elm), (8) *Brevicoryne brassicae* L., (9) *Myzus persicae* Sulz., (10) *Myzus cerasi* F., (11) *Macrosiphum rosaeformis* Das., (12) *Callipterus juglandis* Frisch., and (13) *Shivaphis celti* Das. We have not found it on any other aphid in nature. It is, therefore, concluded that in the Punjab *A. mali* is specific to woolly aphis.

Life-history

On an average the adult parasites live for seven to eight days. They feed on honeydew produced by the woolly aphis. They 'sting' the host, usually near about the mid-dorsal area of the abdomen, two to four days after emergence.

Life-cycle.—The duration of the life-cycle of the parasite depends upon the season as is seen from Table I.

Table I

Duration (in days) of the life-cycle of A. mali *Hald. at Kulu*

Date of egg-laying	Date of emergence of adults	Duration (in days) of life-cycle
8-10 March	2-12 April	25-33
15-18 March	10-12 April	25-26
3-20 April	28 April-15 May	25
3-24 May	23 May-19 June	20-26
12-27 June	30 June-12 July	15-18
12-27 July	27 July-7 August	11-15
2-25 August	13 August-4 September	10-11
5-8 September	17-24 September	12-16
18-20 September	1-8 October	13-18
30 September-15 October	8-24 March	159-160

During June-October the life-cycle is completed in 10-18 days and in March-June in 20-33 days.

The duration of various stages in the life-cycle of the parasite depends upon the season. For example, eggs hatch out in two to three days in March-May, one to two days in June-August and six to seven days in October, while the larvae are full-fed in 8-15 days in March-June, four to six days in July-August, six to seven days in September-October and 121-123 days in October-February, and the pupal stage occupies 11-15 days in March-June, 6-10 days in July-early October and 22-30 days in February-March.

Seasonal history

At altitudes of 4,000—5,000 ft. the adult parasites appear on the wing usually in the first week of March. From March to November all the stages are present in the orchards. During this period it passes through 15 broods as follows :—March ; April ; two broods in May ; June ; June-July ; July ; July-August ; two broods in August ; August-September ; two broods in September ; October ; and November. Elsewhere a maximum of 12 generations in a year is recorded [Greenslade, 1936]. From the middle of November to mid-February, the parasite hibernates as a grub in the body of the host. These grubs change into pupae in the second half of February from which adults appear in the first week of March.

Stage and number of woolly aphis parasitized

A. mali Hald. attacks wingless adults and 4th stage nymphs commonly and 3rd stage nymphs rarely. It never attacks winged adults and 1st and 2nd stage nymphs. It usually attacks the aerial forms only, as it is unable to penetrate the soil to get at the root forms ; but if they are exposed, they are also attacked readily and with equal severity.

In order to study the number of woolly aphis parasitized by a single female parasite they were liberated on infested twigs in glass tubes, the twigs being changed every third day. The results of these observations are presented in Table II.

During the period of maximum activity one female may parasitize as many as 220 woolly aphis.

Recognition of a parasitized aphis

The attacked aphis stops feeding and becomes quiescent soon after parasitization. Its waxy threads start dropping off within two to four days, and its colour starts darkening from pinkish to dark brown, ultimately becoming jet black. It remains fixed to the plant by a secretion (produced under stimulation of parasitization), its rostrum also remains fastened in the plant tissue. The parasite larva eats up the internal organs leaving only a hardened shell behind. Thus a parasitized aphis is devoid of white, waxy filaments, and has a hardened body which is glossy black in colour. The adult parasite comes out of the body of the host by cutting out of a neat circular hole in its hardened body-wall.

TABLE II

Number of woolly aphis parasitized by a female parasite at Kulu

No.	Experiment started on	Date of oviposition	Parasite died on	Number of individuals parasitized
1	2 June . .	4-10 June . .	11 June . .	35
2-4	,, . .	4-15 June . .	15 June . .	220
5-7	4 June . .	6-15 June . .	15 June . .	25-42
	,, . .	7-17 June . .	17 June . .	115
9-11	1 July . .	4-11 July . .	12 July . .	11-72
12	,, . .	4-12 July . .	,, . .	192
13	,, . .	4-12 July . .	,, . .	215
14	,, . .	4-12 July . .	,, . .	187
15	2 August .	5-9 August . .	10 August	13
16-17	,, .	5-10 August . .	11 August .	12-80
18	,, .	4-14 August . .	14 August .	38
19-20	,, .	4-14 August . .	15 August .	15

RANGE OF FLIGHT

In order to study the distance which it will travel (by flying or will be carried by wind) to reach its host from the original point of introduction, the parasite was liberatred only in certain orchards in the Kulu valley. These observations show that it can cover a distance of $2\frac{1}{2}$ miles.

CARE AFTER ESTABLISHMENT

In the Punjab the parasite requires constant care for the following reasons:—

(1) Kulu valley is severely infested with the notorious San Jose' Scale (*Fobesaspis perniciosus* Comst.). The orchardists spray their gardens every winter with diesel oil emulsion to control it [Rahman, 1940]. The spray material kills the hibernating parasite grubs, with the result that in the following spring, the parasite is either absent from, or is present in very greatly reduced numbers in, the treated orchard. Fresh colonies of the parasite have to be introduced to rehabilitate it.

(2) The predators [Rahman and Khan, 1941] such as *Ballia eucharis* Muls., *Oenopia sauzeti* Muls., *Chilomenes bijugus infernalis* Muls., *Syrphus confrater* Wd., *Ancylopteryx punctata* Hog. and red mites feed indiscriminately on woolly aphis. As such they play havoc with the parasite also, particularly during April-August.

In order to protect the prarasite against these calamities, various experiments were carried out, and the following measures were found to give adequate protection :—

(1) *Against diesel oil emulsion.*—The apple twigs bearing a parasitized and healthy woolly aphis were 'planted' in a 4 ft. × 2 ft. × 2 ft. wire-gauze cage towards the end of November and early December near a water channel. They were irrigated or watered with a gardeners' can, etc. regularly twice a week throughout winter. The parasite became active in March and quickly built up an affective population in subsequent months.

(2) *Against predators.*—The apple twigs bearing healthy and parasitized woolly aphis were 'planted' in a 4 ft. × 2 ft. × 2 ft. wire-gauze cage in March-April. These twigs were replaced by freshly cut infested shoots after every 15 days during summer. They were irrigated or watered with a gardeners' can thrice a week during summer. The parasite bred in the cage unmolested, from where it flew out continuously and regularly, and thus maintained its field population at an effective level.

SUMMARY

Woolly aphis (*Eriosoma lanigerum* Hausm.) was introduced into the Punjab in 1909. It is at present found in the Kulu valley and the Simla hills. Its parasite—*Aphelinus mali* Hald.—was successfully introduced and established in the Kulu valley in August 1937.

A. mali has been reported from about 22 different species of aphids from elsewhere, but in the Punjab, it has been found to be a specific parasite of woolly aphis.

On an average the adult parasite lives for seven to eight days. It is active during March-November when it passes through 15 generations. Its life-cycle is completed in 20-33 days in March-June and 11-18 days in June-October. It hibernates as a grub in the body of its host during mid-November to mid-February.

The parasite attacks wingless adults and 4th stage nymphs commonly, and 3rd stage nymphs rarely ; it never attacks winged adults and 1st and 2nd stage nymphs. When its activity is at peak, one female may parasitize as many as 220 woolly aphis. The parasitized aphis loses its white, waxy threads and becomes jet-black in colour ; it remains fixed to the plant. The adult parasite can cover a distance of 2½ miles to reach its host.

After the parasite is established, it requires protection from winter sprays and from predators. The methods to achieve this protection are described.

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SELECTED ARTICLE

THE WATER REQUIREMENTS OF RICE IRRIGATION

BY

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THE future will probably see in China large scale engineering works involving the irrigation of rice. In order that these may be planned to be as efficient as possible, an accurate knowledge is required of the water necessary to irrigate rice, both the total amount required and the distribution of the demand throughout the irrigation season. When rice irrigation is already practised in the region where the works are planned, the best way to secure this information is to measure over a number of years the requirements of small plots already under irrigation. Unfortunately, before construction of a project is authorized, money to carry out such studies is usually not available, and when the project is authorized, construction cannot be postponed until the data is collected. In such a case valuable data can be secured from an investigation of the irrigation requirements in similar regions. When the irrigation project is planned in a region where rice has not been previously cultivated, the only data source is that of other regions.

Since both of these conditions exist in China, it is believed that an investigation of the water requirements under as wide a range of conditions as possible should prove of value in China and in other countries where such projects may be contemplated. The following study was therefore undertaken at the University of Iowa by Messrs Cheng and Pien under the direction of Prof. E. W. Lane, as a subject for their thesis as candidates for the degree of Master of Hydraulic Engineering.

In the following pages are given a summary of the methods of analysis used and the results obtained. It is hoped that additional data on this subject may be secured in order that further studies of this type may be made and a more detailed report prepared giving the results of the entire study.

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TABLE

Summary of the rice irrigation

1	2	3	4	5	6	7	8	9	10	11
					Soil condition				Approximate date of	
Country	State or Province	Location	Period	Area (acre)	Surface soil	Subsoil	Variety of rice	Method of irrigation	First irrigation	Beginning of submergence
U. S. A.	California*	Sacramento Valley	1916—1918	355	Copay clay		Early & late	Canal		
,,	,,	,,	,,	8,477	Willows clay adobe		,,	,,		
,,	,,	,,	,,	5,057	Willows clay		,,	,,	April 13 to May 22	May 19 to July 12
,,	,,	,,	,,	2,877	Stockton clay adobe		,,	,,		
,,	,,	,,	,,	4,653	Sacramento clay		,,	,,		
,,	,,	,,	,,	267	Tehoma clay loam & clay		,,	,,		
,,	,,	,,	,,	302	Vina clay loam		,,	,,		
,,	,,	,,	,,	45	Willows loam & clay		,,	,,		
,,	,,	,,	,,	122	Willows loam		,,	,,		
,,	,,	,,	,,	51	Sam Joaquin loam		,,	,,		
,,	,,	(d) Biggs	1914—1917	71	Stockton clay adobe		,,	,,	April 15	June 9
,,	Arkansas	Arkansas County	1928—1929	1,088	Crowley silt loam	Impervious clay	Early & late	Pumping	May 20 to June 10	
,,	Texas†	...	...	...	,,	,,		,,	May	July
,,	Louisiana†	Crowley	1917—1919	...	,,	,,	Early & late	Pumping	May	July
China	Kiangsu	Wukiang Hsien	1934—1935	...	Clay		Early		April 25 to April 30	June 1 to June 8
,,	,,	Wuchin Hsien	1928—1935	5,380	Impervious clay		Late	Pumping	May 5-10	June 10
,,	Kwangtung ‡	Canton	1927—1929	...	Clay loam		Early		April 20	May 5
,,	,, ‡	,,	,,	...	,,		Late		July 21	Aug. 5
Indo-China	Annam§	Thank Hoa	...	111,195	Clay			Canal	June 11	July 1
Java	Tangerang‖	...	...	...	Clay				Nov.	
(i) India	Madras¶	Maruteru	1937	495	Clay			Canal	June 26	July 11

(a) Average value of 1916 records in Sacramento Valley. Bull. No. 279, Agriculture Experiment Station, University of California.

(b) Humidity, wind velocity, and temperature are the mean value and the rainfall is the average total value, from June to October, for the 5-year period from 1914 to 1918 at Sacramento Cal.

(c) Evaporation is the average total from April 16 to Sept. 30 for 11-year period, from 1926 to 1936, at Davis, California.

(d) E. I. Adams Rice Field near Biggs is also in Sacramento Valley.

(e) Weight per bushel of rice is 44·05 lbs. which is the average value in Texas. Varieties of Rice for 'Texas' Bull. No. 485, Texas Agriculture Experiment Station.

(f) The climatological data except rainfall are the records observed at the Rice Branch Experiment Station.

in various countries

2	13	14	15	16	17	18	19	20	21	22	23	24	25	26
ion	Average length of irrigation season			Average net depth of water used				Climatological conditions during irrigation season						
												Monthly temperature		
e of er d off	Prior to sub-merg-ence (day)	Period of sub-merg-ence (day)	Total (day)	Prior to sub-merg-ence (in.)	During sub-merg-ence (in.)	Total depth applied (in.)	Yield of rough rice per acre (lb.)	Average seasonal rainfall (in.)	Av-erage season-al evapo-ration (in.)	Average seasonal humidity per cent	Average seasonal wind velocity (mil./hr.)	Max. (°F.)	Min. (°F.)	Mean (°F.)
			159			47·50								
			154			50·60								
. 27			168			61·00								
o 30			157			61·60								
			167	9·85 to 26·80		68·60	(a) 2,940	(b) 1·51	(c) 49·28	(b) 56	(b) 7·7			(b) 70
			173			97·50								
			153			97·50								
			155			80·20								
			170			112·60								
			174			140·50								
t. 30	55	114	169	13·20	41·20	54·40	4,600	2·77	38·84		4·4	111	28	
. 20 to t. 20			90-105		29·85		(e) 2,458	11·25	(f) 31·37	(f) 80·9	(f) 2·6	(f) 87·6	(f) 64·2	(f) 75·9
t.						31—37		(g) 18·00	21·35	82·8	3·6	89·7	70·5	80·1
t.	15—40	55—92	90-120		28·04		2,000	(h) 19·35	23·00		1·8			80
. 18 to . 23	23	77	100		35·90			19·55	19·36	84				81·1
t. 20	33	102	135			38·00		21·94	27·00					
y 28	15	84	99	5·12	19·55	24·67		16·40						81·4
. 3	15	91	106	5·12	26·00	31·12		13·80						80
. 30	20	153	175			51·33		29·51	23·77					
r.	49	84	133	15·68	28·33	44·01		47·70	23·55	84				80
. 27	15	139	154	7·86	51·79	59·65		29·00	35·82			86·8	74·8	80·8

(g) Climatological data are the average value between May 15 to Sept. 15.
(h) All the climatological data are average values or average total values from June to September, for the 3-year period from ' to 1919.
(i) The data were supplied by H. T. Wang, a Chinese Government engineer with irrigation experience in India.
*The daily range of temperature in State of California is about 40°F. Trouble of water grass.
†Duty of water estimated by Prof. W. B. Gregory not including the waste for Texas and Louisiana.
‡Seepage loss is low due to high under ground water table.
§Data for October season.
‖Data for wet season.
¶First crop paddy.

SUMMARY OF OBSERVED DATA ON WATER REQUIREMENTS

The first step in this study was the collection of all available information on the water required by growing rice, and the meteorological and other conditions under which these quantities were required. The localities from which the data were obtained are as follows :

(1) Sacramento Valley, State of California, U. S. A.

(2) Arkansas County, State of Arkansas, U. S. A.

(3) State of Louisiana, U. S. A.

(4) State of Texas, U. S. A.

(5) Wukiang Hsien and Wuchin Hsien, Kiangsu Province, China

(6) Canton, Kwangtung Province, China

(7) Thank-Hoa, Annam, Indo-China

(8) Tangerang Werken, Java

(9) Maruteru, Madras Province, India

At Wukiang, Wuchin, Tangerang, Thank-Hoa and Maruteru, not only was the total requirement of water in the rice field determined, but also the amount of water used during each stage of the plant growth. In Louisiana, Wukiang, Canton, and Annam, the loss from field evaporation, transpiration, and seepage was also determined. The results of experiments and estimations of the duty of water for rice in various localities are summarized in Table I, which also gives data on the classification of soil, variety of rice, and average climatological conditions.

A study of Table I shows a wide range in the amount of water used, varying from 24·67 inches to 140·50 inches due to the difference in environmental conditions. The chief causes of this wide variation may be summarized as follows :

(1) In the State of California, U. S. A., the net duty of water varie from 47·5 inches to 140·5 inches, undoubtedly due to the variation in the nature of the soil, since all of the data in California were observed in the same district of the Sacramento Valley, there being no material difference in the climatological conditions.

(2) In the rice sections of the states of Arkansas, Texas and Louisiana the water requirements for rice irrigation are nearly equal, averaging about thirty inches. The reasons for this condition are the similar soils, subsoils, and climatological conditions.

(3) Comparing the data observed in California with that from Arkansas, Texas, and Louisiana, it is found that more water is required in the California district than in the latter, probably due principally to the difference in climate. In the state of California, the total evaporation during irrigation season is about 49 inches, and the mean monthly temperature is 70° F. In the three southern states the total evaporation during irrigation season is about 22 inches, and the mean monthly temperature is about 80° F. The evaporation in California is much higher, in spite of the lower temperature, because of the lower humidity and higher wind velocity.

(4) In the Kwangtung experiments, the water requirements for both the early and late rice were smaller than those in Kiangsu. The reason seems to be the low transpiration loss in Kwangtung. The reason for the low transpiration loss cannot be determined because of the lack of the necessary climatological data. Another reason for the lower requirements for early rice in the Kwangtung experiment, as compared with those in Kiangsu, is the lower seepage loss in the former experiments resulting from a high water table, and higher seepage in the latter because the experiments were carried on in a new field.

(5) In Indo-China the data presented are only the estimates used in design of the rice irrigation projects, and these estimated values may be higher than the actual amount of water required since the evaporation loss was assumed equal to the free water surface evaporation.

(6) Because of the higher evaporation and longer irrigation season in India, the observed value is very large.

Analysis of observed data and development of method of determining water requirements of rice

The four major divisions into which the duty of water for rice irrigation may be divided are as follows:

(1) the evaporation from the water surface of the rice field,

(2) the transpiration of water by the rice plants,

(3) the seepage of water out of the rice field through the ground,

(4) the initial application of water necessary to prepare the land for cultivation and to supply the water required for the first submergence.

The first three of these divisions will be handled as a group and classified as losses during the submergence period. The proportion of each of the three losses during the period varies widely with the soil texture, variety of rice, method of irrigation, length of irrigation season, difference of climate, and other conditions of irrigation practice. The proportions of the total water used in the three divisions in the various localities are shown in Table II.

Table II

Consumption of irrigation water in rice fields during period of submergence

Country	Locality	Loss by evaporation		Loss by transpiration		Loss by seepage		Total	
		in.	Per cent	in.	Per cent	in.	Per cent	in.	Per cent
U. S. A.	Louisiana	10·10	36·00	16·38	58·50	1·56	5·50	28·04	100
China	Wukiang	8·64	23·70	15·48	43·20	11·88	33·10	35·90	100
China	Canton	9·28	47·50	6·85	35·00	3·42	17·50	19·55	100
China	Canton	13·00	50·00	6·63	25·50	6·37	24·50	26·00	100
Indo-China	Annam	...	...	19·70	...	...	...	...	...
	"	...	...	16·42	...	...	...	...	...

The distribution of the loss among the three items is not uniform during the whole irrigation season. In general, the field evaporation is greater in the first part of the irrigation season and smaller in the latter part, while the loss from transpiration is smaller in the first of the season and greater during the latter. Fig. 1 was prepared to illustrate this fact, using the data of Pansan Rice Field Experiment Station, Kiangsu, China, in 1934 and 1935. These losses are discussed in detail in the following paragraphs.

(1) Loss by field evaporation

The soil in the rice field is submerged in water to a depth of several inches during most of the growing season. The majority of the factors affecting field evaporation, such as temperature, wind velocity, and relative humidity, are the same as those affecting evaporation from a free water surface. The only other important factor influencing field evaporation is the effect of the stage of growth of the rice plants. When this factor is considered, the loss by evaporation from a free water surface will give a general indication of the loss from the field.

A summary of observed data showing the relation between field evaporation and evaporation from a free water surface is given in Table III.

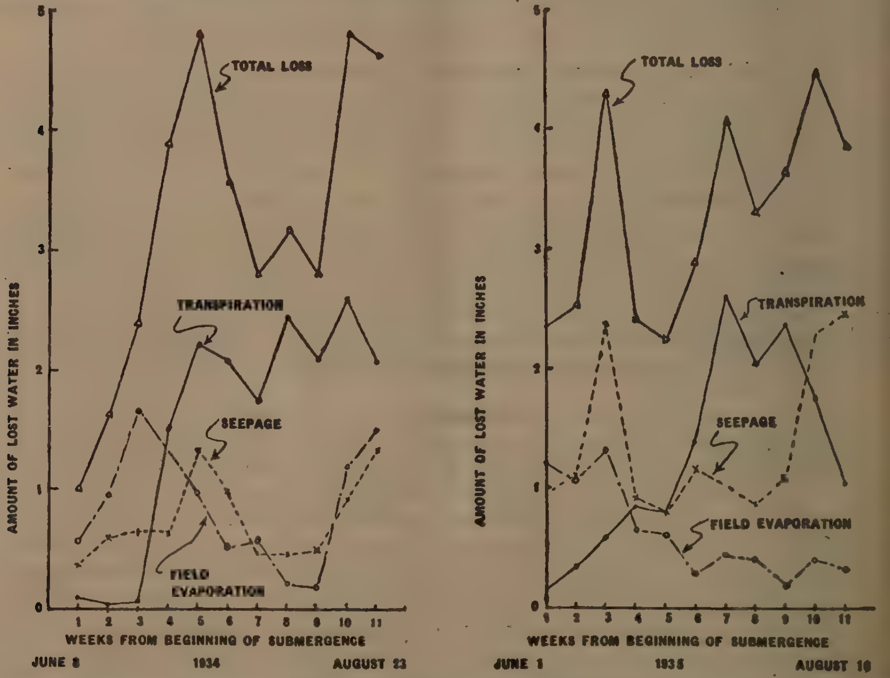


FIG. 1. Relation of lost water from evaporation, transpiration and seepage during period of submergence, Wukiang, China

TABLE III

Evaporation in rice field during period of submergence

Location	Field evaporation (inches)	Evaporation from a free water surface (inches)	Remarks
Louisiana, U. S. A.	10·10	15·72	
Wukiang, China	8·54	12·80	Early rice
Canton, China	9·28	11·05	Early rice
Canton, China	13·00	17·34	Late rice

By plotting these data on logarithmic paper, a relation between the field evaporation and the evaporation from a free water surface was found which may be expressed approximately by the following equation :

$$E_f = 1 \cdot 8E^{2/3}$$

where E_f = total field evaporation in inches during the period of submergence.
E = total evaporation in inches from a free water surface during the same period.

The data on total evaporation from a free water surface which have been collected during the submergence season vary from 11 to 35 inches. To obtain reasonable results in using this equation, only evaporation records which come within these limits should be used.

For determining the distribution of this loss during the irrigation season, further study is required. The only data showing the effect of the stage of growth of rice plants on the field evaporation is that from the Pansan Rice Field Experiment Station, Wukiang, China, shown in Fig. 2.

From this curve, it will be seen that during the first part of the submergence period the cumulative field evaporation is nearly equal to that from the free water surface, and during the remainder of the submergence period, the cumulative field evaporation varies approximately as a straight line, but is less than the water surface evaporation. During the first part of the season, the field is open water and has practically the same evaporation as a free water surface ; but after about 40 per cent of the season has elapsed, the shading effect of the growing plants becomes appreciable, and the rate of evaporation is materially reduced.

In computing the distribution of field evaporation loss throughout the season for any locality, the evaporation for the first 40 per cent of the period is considered equal to the free water surface evaporation, and the distribution for the remaining 60 per cent is assumed to be constant at the rate which will bring the total to the value $1 \cdot 8E^{2/3}$. When this method was applied to the records where water surface evaporation records were available, values were found from which a generalized diagram (Fig. 3) was prepared showing the ratio of the accumulated field evaporation to the accumulated water surface evaporation throughout the submergence season. These ratios differed somewhat depending upon the total water surface evaporation. This diagram enables an estimate to be made of the amount necessary to supply the evaporation requirements of rice at any time during the submergence period, if the evaporation data are available, by subtracting the accumulated value at the beginning of the time interval from that at the end of the interval.

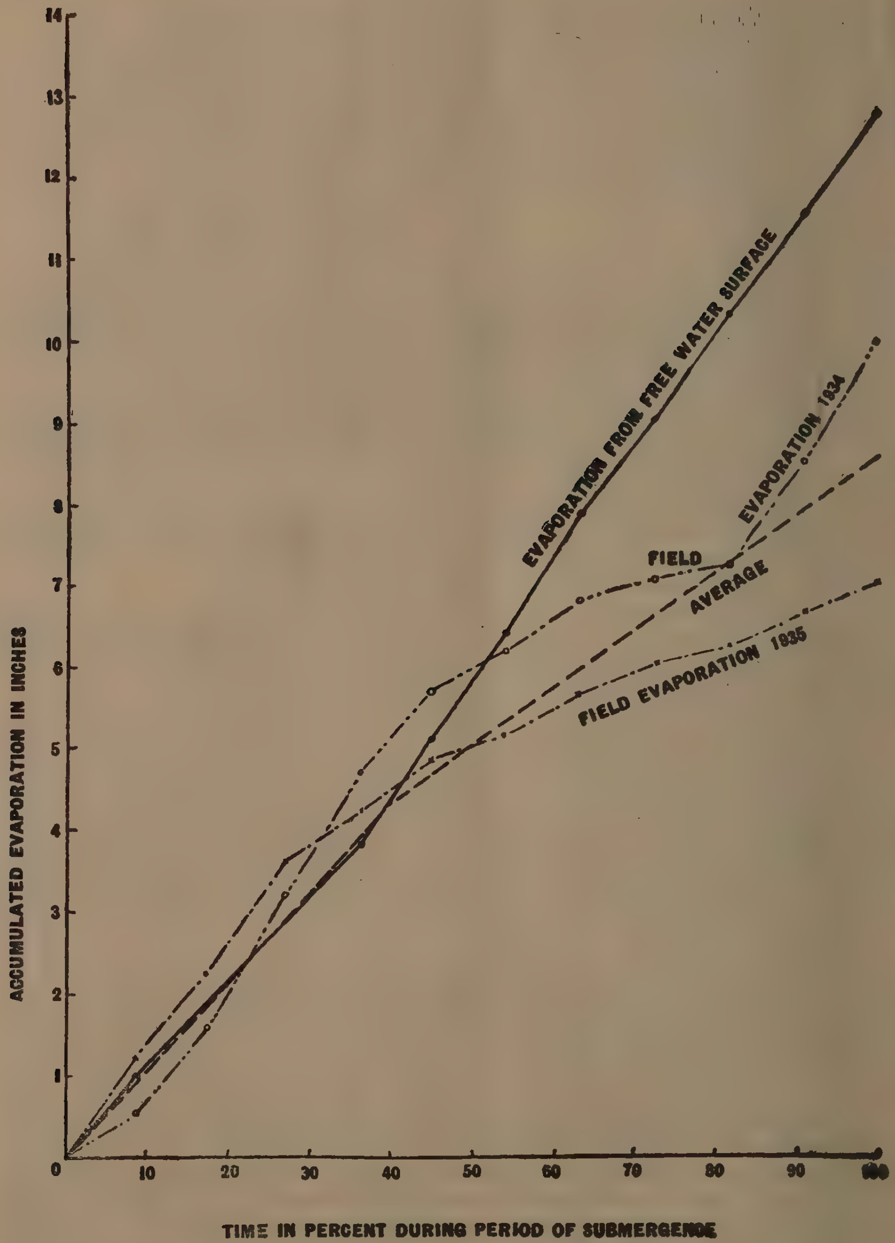


FIG. 2. Mass curve of field evaporation during period of submergence, Wukiang, China

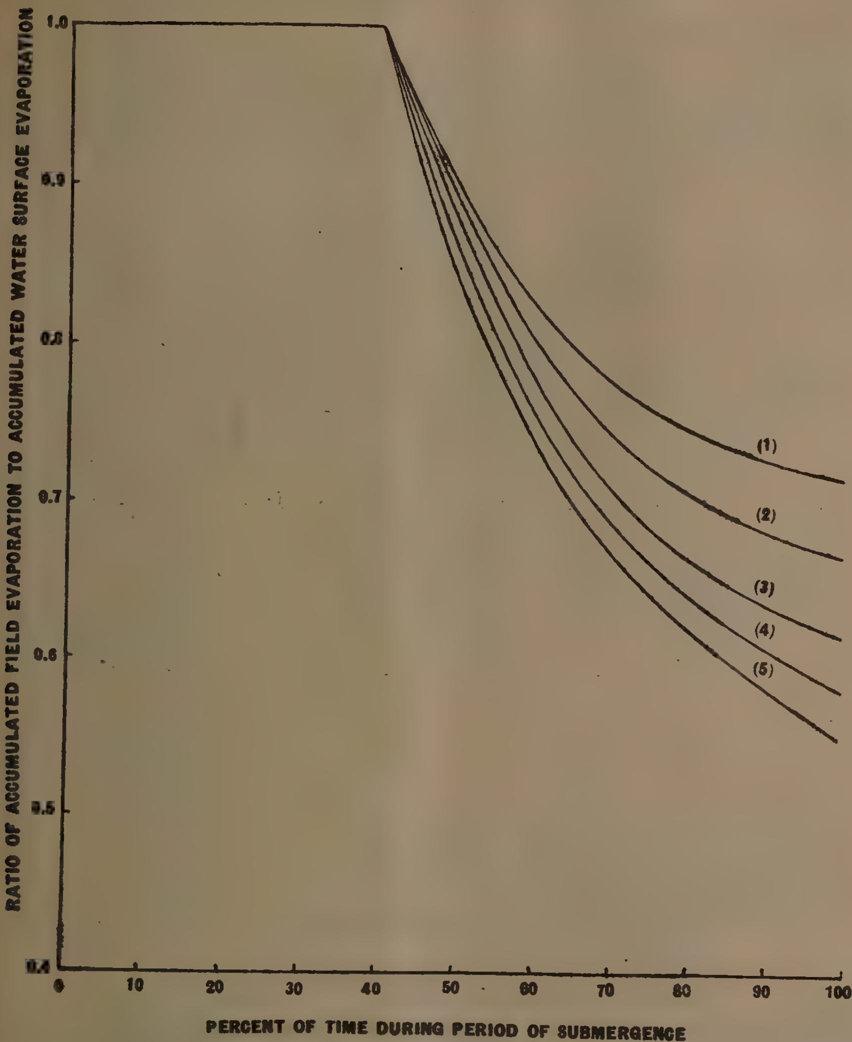


Fig. 3. Various ratios of accumulated field evaporation to accumulated water surface evaporation

(1) For water surface evaporation during period of submergence 15 inches
(2) ,, ,, ,, ,, ,, ,, 20 ,,
(3) ,, ,, ,, ,, ,, ,, 25 ,,
(4) ,, ,, ,, ,, ,, ,, 30 ,,
(5) ,, ,, ,, ,, ,, ,, 35 ,,

(2) LOSS BY TRANSPIRATION

The main factors affecting transpiration in rice fields are much the same as those affecting evaporation from a free water surface. In Table IV are collected all available data on evaporation and transpiration during the submergence period. The ratio of transpiration to evaporation has been computed also.

TABLE IV

Total transpiration and evaporation during submergence season

Experiment station	Submergence season	Transpiration during submergence (in.)	Evaporation during submergence (in.)	Ratio of transpiration to evaporation	Remarks
Wukiang .	June 1 to Aug. 16	15·48	12·79	1·21	Mean value from 1934-1935
Louisiana .	July 1 to Sept. 30	16·62	15·72	1·03	Mean value from 1910-1917
Texas	July 1 to Sept. 30	16·50	15·53	1·06	Mean value estimated by Prof. W. B. Gregory
Annam .	July 1 to Nov. 30 (Oct. season)	19·68	20·08	0·83	Estimated value for computation of duty of water

These data were plotted on logarithmic paper with evaporation from the free water surface against the transpiration, and the equation $P=6\cdot6E^{1/3}$ was derived in which

P=total amount of transpiration of rice plants during submergence period, in inches.

E=total amount of evaporation from free water surface during submergence period, in inches.

The distribution of the transpiration and the field evaporation throughout the submergence season was also determined. Data were available from Annam, Louisiana, and Wukiang giving both the transpiration and the evaporation losses throughout the season. The variation of these is shown in Fig. 4. Using these data and the relation $P=6\cdot6E^{1/3}$ for the total transpiration at the end of the season, a generalized diagram (Fig. 5) was prepared showing the ratio of the accumulated transpiration to the accumulated water surface evaporation during the submergence period for various values of total water surface evaporation. From this diagram it is possible to determine the rate of water use for transpiration for any short period by finding the accumulated total at the beginning and end of the period.

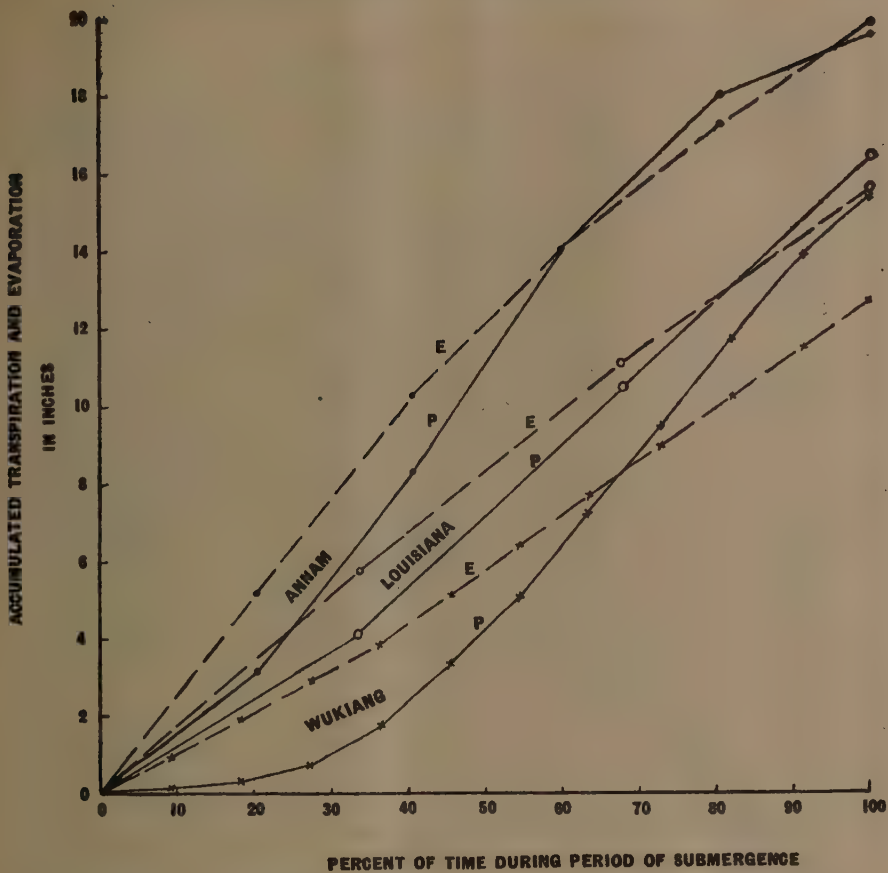


FIG. 4. Mass curve of transpiration and water surface evaporation during period of submergence at Annam, Louisiana and Wukiang

E=Water surface evaporation ; P=Transpiration

(3) LOSS BY SEEPAGE

The most important factor affecting the amount of seepage is the character of the soil. Other factors, such as temperature, depth of water in rice field, ground water table, and age of the rice field, also affect the amount of percolation.

It is very difficult to measure directly the actual amount of percolation. In general, the field observations of percolation are made by subtracting the other losses from the total loss and charging the remainder to percolation. Some observed data obtained in this manner are given in Table V.

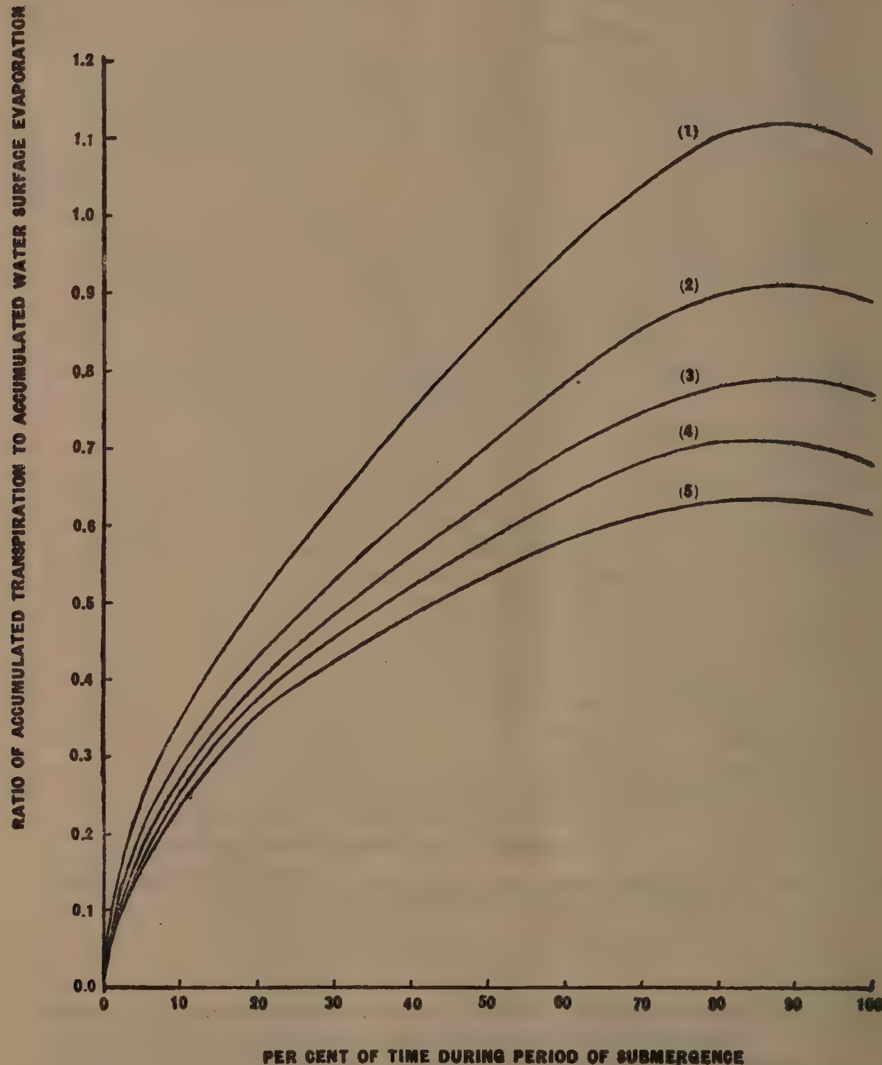


FIG. 5. Various ratios of accumulated transpiration to accumulated water surface evaporation

(1) For water surface evaporation during period of submergence 15 inches
(2) " " " " " " 20 "
(3) " " " " " " 25 "
(4) " " " " " " 30 "
(5) " " " " " " 35 "

TABLE V

Observed data of seepage loss

Location	Soil class	Length of season (days)	Total seepage (in.)	Daily loss of seepage (in.)	Remarks
Louisiana, U. S. A.	Silt loam over impervious clay	92		0·017	Average value of 4″ to 6″ depth of water during submergence
Wukiang, China	Clay . .	77	11·88	0·154	New rice field
Canton, China	Clay loam .	84	3·42	0·041	Underground water table is high
Canton, China	,, ,, . .	91	6·37	0·071	Underground water table is high

The surface soil in the state of Louisiana is Crowley silt loam, while the subsurface soil is an impervious clay. The daily seepage loss of 0·017 inch observed in this region may be considered as a minimum value for the impervious clay subsoil. In the state of California, some data are available on the duty of water, which give the classification of soil,and are very valuable for the comparison of seepage losses. Assuming the daily loss of seepage for Willows clay adobe to be 0·017* inch, the same as in the state of Louisiana, and the seepage loss to be uniformly distributed during the whole irrigation season, the daily loss by seepage for the other classes of soil is estimated in Table VI.

TABLE VI

Estimated daily loss of seepage for various classes of soil in state of California

Soil class	Length of whole irrigation season (days)	Total net depth of water applied (in.)	Estimated loss by seepage (in.)	Daily loss by seepage (in.)	Average daily loss by seepage	(in.)
Willows clay adobe .	154	50·60	2·62	0·017	Clay	0·076
Willows clay . .	168	61·00	13·02	0·077		
Stockton clay adobe	157	61·60	13·62	0·087		
Sacramento clay .	167	68·60	20·62	0·123		
Willows clay loam .	155	80·20	32·22	0·208	Clay loam	0·273
Tehama clay loam .	172	97·50	49·52	0·288		
Vina clay loam .	153	97·50	49·52	0·323		
Willow loam . .	170	112·60	64·62	0·380	Loam	0·456
San Joaquin loam .	174	140·50	92·52	0·532		

* Later studies show that this is probably too low and should be about 0·020.

For general application, the range of daily loss by seepage in rice field for the different soils is summarized in Table VII.

TABLE VII

Daily loss of seepage for various ordinary classes of soil

Soil class	Daily loss of seepage (in.)	Average daily loss of seepage (in.)
Impervious clay	0 —0·050	0·025
Clay adobe	0·050—0·100	0·075
Pervious clay	0·100—0·150	0·125
Clay loam	0·150—0·350	0·250
Loam	0·350—0·550	0·450

Only from the state of Louisiana were data available on the mechanical analysis of surface soil and subsoil and permeability tests of the soil. Based on the results of seepage losses found in Tables VI and VII, a tentative chart (Fig. 6) was prepared for the determination of daily seepage for different soils at a mean temperature of 70° F. The percolation values obtained from this chart should be increased by about $1\frac{1}{4}$ per cent per degree Fahrenheit for average temperatures above 70° and correspondingly decreased for values below. The chart is based upon comparatively little data and therefore it is given tentatively with the hope that more data may become available by means of which the chart can be revised.

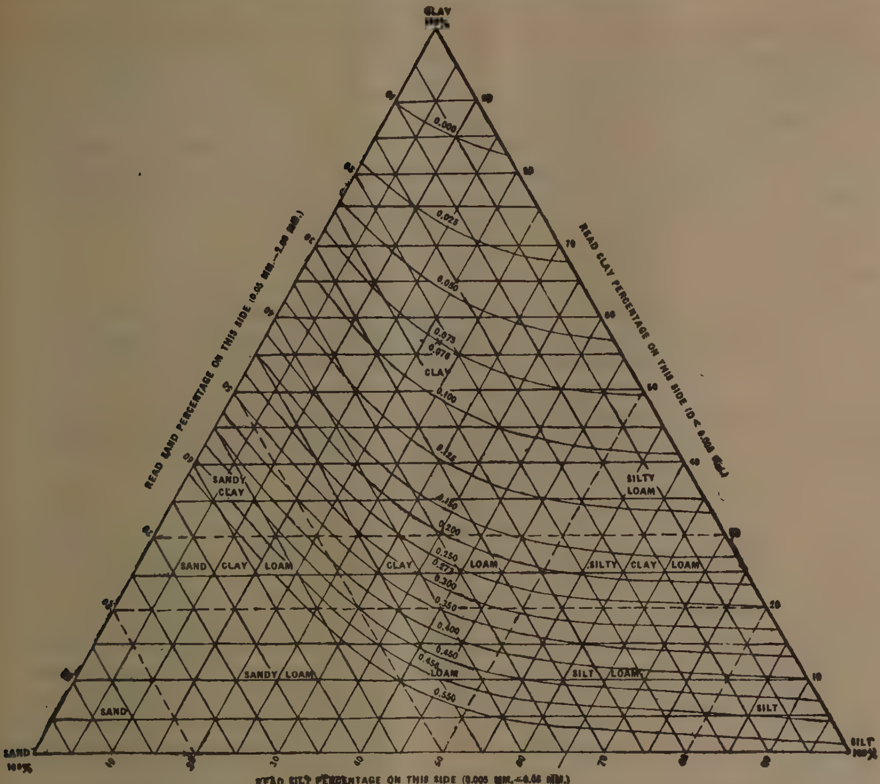
(4) WATER REQUIRED BEFORE SUBMERGENCE

There are two seeding methods which are generally used in various countries : (1) the broadcast method, generally used in the United States ; and (2) the transplanting method, generally used in Asia.

In the Sacramento Valley, California, where the broadcast method was used, the amount of water required in 1916 prior to submergence was determined for different soils. The total amount of water used before submergence minus the uniform seepage loss during the period for the particular type of soil (assumed at the same rate as during the submergence period) gave about 4 inches as the average required for initial submergence.

In the experiment made by the College of Agriculture, National Chunsan University, Canton, China, where the transplanting method was used, the water required was 5·17 in. for the 15 days before submergence. The average daily seepage was 0·059 inch. The difference between the total amount required and the total seepage before submergence was nearly 4 inches.

Since the water used before submergence in both cases may be represented by the same factors, it is thought that the water required before submergence may be estimated by the formula, sl_1+4, in which s is the daily seepage in inches and l_1 is the length of the period before submergence.



F G. 6. Tentative chart for the determination of daily seepage (in.) for different kinds of soil at 70°F.

(5) EMPIRICAL FORMULA FOR ESTIMATION OF NET DUTY OF WATER FOR RICE

The consumption of water in the rice field, the field evaporation, transpiration, seepage, and the water required before submergence, have been investigated separately. Combining the four factors, the total net duty of water for rice (excluding the losses beyond the rice field) throughout the irrigation season is $D=6\cdot 6E^{1/3}+1\cdot 8E^{2/3})sL+4$. In order to simplify the equation the values of the sum of $6\cdot 6E^{1/3}$ and $1\cdot 8E^{2/3}$ were plotted against E on logarithmic paper and the following formula obtained: $6\cdot 6E^{2/3}+1\cdot 8E^{2/3}=7\ E^{1/2}$.A more simple formula is therefore suggested, which is

$$D=7E^{1/2}+sL+4$$

in which

D=the total net duty of water in inches for rice.

E=total evaporation in inches from a free water surface during submergence period.

s=average daily seepage in inches in rice field during entire irrigation season.

L=total days during irrigation season.

In any locality where the length of irrigation season, the total evaporation during the submergence season, and the soil characteristics are known, the total approximate net duty of water required for rice may be found from the equation given.

If there are no records of evaporation in the locality, the total evaporation may be estimated from hydrological data by evaporation formulas such as that of Meyer*,

$$E=15\ (V-u)\ (1+\frac{W}{10})$$

in which

E=evaporation in inches depth per 30-day month

V=maximum vapor pressure in inches of mercury corresponding to monthly mean air temperature observed by Weather Bureau at nearby stations.

u=actual pressure of vapor in air based upon Weather Bureau determinations of monthly mean air temperature and relative humidity at nearby stations.

W=monthly mean wind velocity in miles per hour about 30 ft. above general level of surrounding country or roofs of city buildings.

In order to determine the probable accuracy of the results obtained with this formula, a comparison has been made between the observed values and those computed by the formula for all cases in which the data were available. The results of this comparison are shown in Table VIII. From the table it may be seen that only in the case of Canton, China, was the difference between computed and observed values large. The discrepancy seems to be largely in the item of transpiration, the observed transpiration at Canton for no evident reason being considerably less than that at any other place covered by the records.

(6) Graph for estimation of distribution of net duty of water

In the design of canals for an irrigation project, the maximum amount of water required during any interval of time is more important than the average amount of water required during the whole irrigation season. The empirical formula previously developed can only be used to estimate the total net duty of water for the whole irrigation season. Therefore, a study of the distribution of irrigation water during the season is necessary.

The most important factor affecting the distribution of irrigation water is the stage of growth of the rice plant, which affects field evaporation and transpiration as shown in Figs. 3 and 5. Combining Figs. 3 and 5, the distribution graph for field evaporation and transpiration is given in Fig. 7.

The distribution of the water required throughout the season can be estimated from the distribution graph (Fig. 7) by: (1) assuming that the seepage losses are uniformly distributed during the whole irrigation season and obtaining the amount of daily seepage loss from Fig. 6, (2) adding the amount of water for initial flooding, (3) estimating the amount of water required for transpiration and evaporation.

* *Engineering News-Record*, Aug. 6, 1936, *Graphical aid in the solution of Meyers' evaporation formula* by A. S. Levens

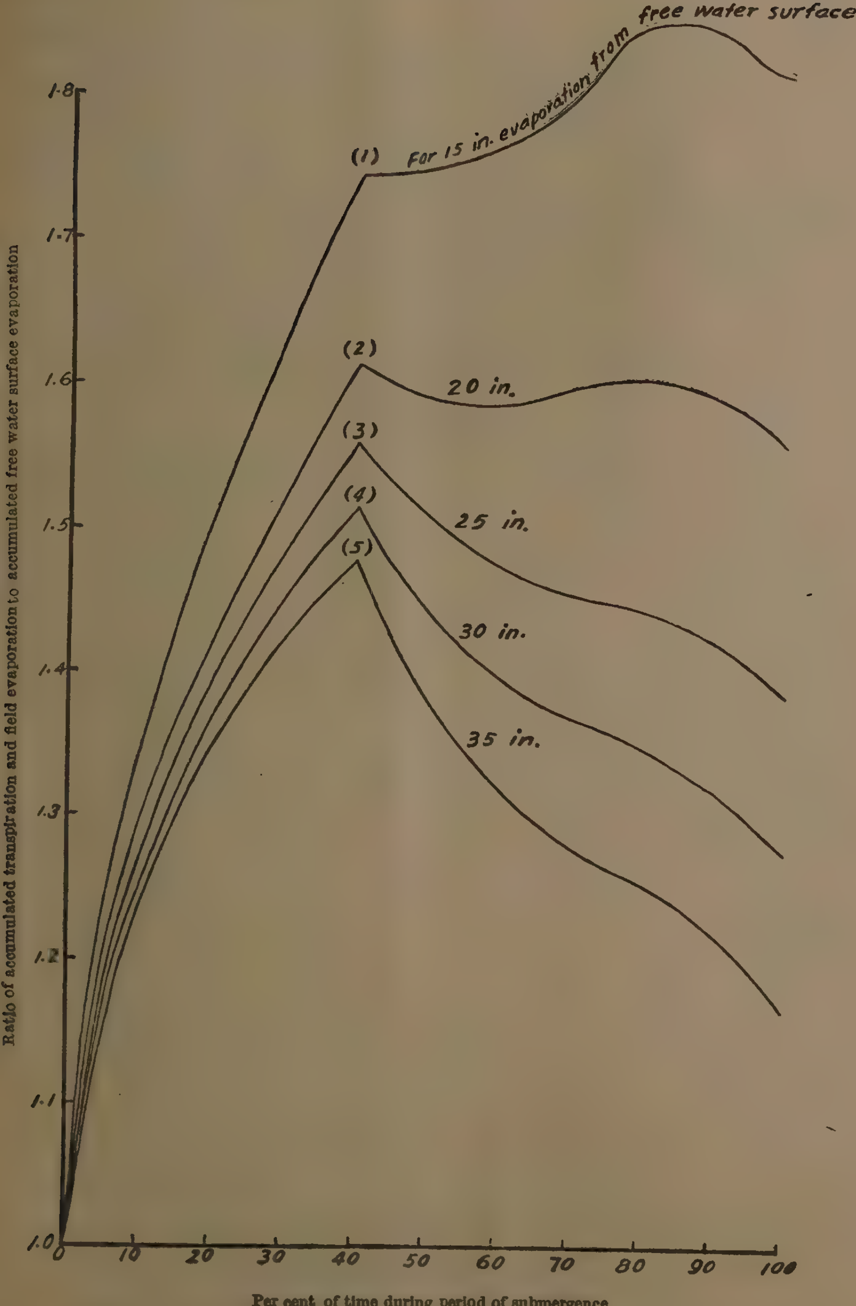


Fig. 7. Distribution graph for field evaporation and transpiration

TABLE

Comparison of observed and computed total

Country	Location	Period	Soil condition	Approximate date of irrigation		
				First irrigation	Beginning of submergence	End of submergence
U. S. A.	Sacramento Valley, California	1916—1918	Capay clay	Ave. April 21 From April 14 to May 22	Ave. June 11 From May 19 to June 12	Ave. Sept. 30 From Sept. 27 to Oct. 30
			Willows clay adobe			
			Willows clay			
			Stockton clay adobe			
			Sacramento clay			
			Tehama clay loam and clay			
			Vina clay loam			
			Willows loam & clay			
			Willows loam			
			San Joaquim loam			
	Biggs, Calif.	1914—1917	Stockton clay adobe	April 15	June 9	Sept. 30
	Arkansas	1928—1929	Surface soil is silt lam. Subsoil is impervious clay	May 20	July 1	Sept. 30
	Texas					
	Louisiana	1917—1919				
China	Wukiang, Kiangsu	1934—1935	Clay	May 9	June 1	Aug. 16
	Wuchin, Kiangsu	1928—1935	Impervious clay	May 9	June 11	Sept. 20
	Canton, Kwangtung	1927—1929	Clay loam	April 20	May 5	July 28
	Canton, Kwangtung	1927—1929	Clay loam	July 21	Aug. 5	Nov. 3
Indo-China	Thank-Hoa, Annam		Clay	June 11	July 1	Nov. 30
Java	Tangerang		Clay	Nov.		Mar.
India	Maruteru	1937	Clay	June 26	July 11	Nov. 27

VIII

net duty of water for rice in various countries

Average length of irrigation season, days: Prior to submergence	Average length of irrigation season, days: During submergence	Average length of irrigation season, days: Total	Observed total evaporation during submergence (in.)	Average seasonal temperature (°F.)	Daily loss of seepage obtained from fig. 6 at 70°F(a) (in.)	Computed total net duty of water (in.)	Observed total net duty of water (in.)	Variation from observed value (per cent)	Remarks
		159			0·017	48·1	47·5	+ 1·3	(a) All daily losses of seepage are the average values which are obtained from fig. 6. (b) The correction of seepage for the effect of temperature is 1¼ per cent per degree Fahrenheit. (c) In Annam there was no temperature record and therefore no correction is made. (d) In Wukiang due to the new rice field the seepage was very high and in Canton due to high ground water table the seepage was very low, therefore the original seepag data are used in these special cases. (e) In these three States, all conditions in the rice field were nearly the same. There were no complete records at hand and can only check with 31″—37″ which was estimated by Prof. W. B. Gregory. The total water used during submergence in Arkansas was 29·85″ and in Louisiana was 28·04.″
		154			0·017	48·1	50·6	— 4·9	
		168			0·075	58·1	61·0	— 4·8	
Ave.	Ave.	157	Ave. 35·13 (It is the average value from 1926 to 1936 a Davis)		0·075	57·3	61·6	— 7·0	
51	112	167		70·0	0 075	58·0	68·6	—15·4	
		172			0·300	97·1	97·5	— 0·4	
		153			0·300	91·5	97·5	— 6·2	
		155			0·300	92·0	80·2	+14·8	
		170			0·450	122·0	112·6	+ 8·4	
		174			0·450	123·9	140·5	—11·8	
55	114	169	29·42	70·0	0·075	54·6	54·4	+ 0·6	
41	[illegible]	120	15·72	80·1	0·017	34·09 (b)	34·0 (e)	+ 0·4	
23	77	100	12·79	81·1	0·154 (d)	44·40	No		
33	102	135	20·00	81·1	0·017	37·91 (b)	38·00	— 0·2	
15	84	99	11·05	81·4	0·041 (d)	31·25	24·67	+26·6	
15	91	106	17·34	80·0	0·071 (d)	40·63	31·12	+30·6	
20	153	173	20·08		0·075	48·50 (c)	51·33	— 5·6	
49	84	133	14·90	80·0	0·075	42·25 (b)	44·01	— 4·0	
15	139	154	31·59	80·8	0·075	57·20	59·65	— 4·0	

Table IX

Computation of duty of water at Biggs Rice Field, California, by distribution graph

1	2	3	4	5	6	7	8	9	10	11	12	13	14
			Per cent of time during period of submergence		Observed evaporation from free water surface								
Month	Approximate date of irrigation season	Number of days	Monthly	Accumulated	Monthly (E)	Accumulated ΣE	Ratio of accumulated field evap. and transpiration to accumulated water surface evap.	Accumulated field evap. and transpiration at end of month $\Sigma(Ef+P)$	Field evaporation and transpiration during each month $(Ef+P)$	Seepage for each month (S)	Minimum water required for initial flooding	Total water required for each month	Capacity required Q
		days	Per cent	Per cent	in.	in.	$R=\frac{\Sigma\,(Ef+P)}{\Sigma E}$	in.	in.	in.	in.	in.	c.f.s./acre
April	Date of first irrigation April 15	16								1·20	4·00	5·20	0·0137
May		31								2·33		2·33	0·0032
June	Beginning of submergence June 9	8 22	19·3	19·3	6·34	6·34	1·357	8·60	8·60	0·60 1·65		10·85	0·0152
July		31	27·2	46·5	9·32	15·66	1·467	23·00	14·40	2·33		16·73	0·0227
Aug.		31	27·1	73·6	7·73	23·39	1·365	31·90	8·90	2·33		11·23	0·0153
Sept.	End of submergence Sept. 30	30	26·4	100·0	6·03	29·42	1·275	73·55	5·65	2·25		7·90	0·0111
Total or average		169							37·55	12·69	4·00	54·24	0·0135

The following example shows the method applied to the duty of water at the Biggs Rice Field in California.

Given conditions.

Location: Biggs Rice Field, California, U.S.A.

Soil: Stockton clay adobe.

Average date of irrigation season:

Date of first irrigation, April 15.

Date of beginning of submergence, June 9.

Date of end of submergence, September 30.

Data on evaporation from free water surface:

Use the mean observed value for the Biggs Rice Field Station from 1914 to 1917.

Length of irrigation season:

Before submergence 55 days.

During submergence 114 days.

Total submergence 169 days.

The steps of the computations are given in Table IX.

Conclusions

In this paper data has been collected from California, Arkansas, Texas and Louisiana in the United States, Kiangsu and Canton provinces in China Annam in Indo-China, Tangerang in Java, and Madras Province, India. The total net duty of water for rice ranged from 24·67 inches at Canton to 140·5 inches in California.

The principal factors in the consumption of water in rice fields are: (1) field evaporation, (2) transpiration, (3) seepage, and (4) preparation of land or initial flooding. The conditions which have the most important effect upon these factors are: (1) climatic conditions, (2) characteristics of soil, (3) length of irrigation season, (4) ground water table, (5) yield, and (6) method of planting.

The temperature, humidity, and wind velocity are the main factors affecting field evaporation and transpiration in rice fields, as well as evaporation from a free water surface.

The characteristics of the soil have an important effect upon seepage. In the Sacramento Valley, California, the climatic conditions are nearly the same, but the average net duty of water varied from 47·5 inches for Capay clay to 140·5 inches for San Joaquin loam. This difference was due mainly to the varied seepage rates in the different types of soil.

In addition to the type of soil, the ground water table is an important factor in seepage. In Canton, the soil was clay loam, but the average daily loss by seepage for early and late rice was 0·056 inches, which was less than that of other localities owing to the high ground water table. The age of the rice field also may affect the rate of seepage. In Wukiang the soil was clay, but the average daily loss of seepage was 0·154 inch, which was greater than for the same type of soil at Wuchin, because the Wukiang field was new.

The irrigation season not only depends upon the kind of rice but also is affected by the climatic conditions. The average temperature in California is lower than in other rice growing sections and therefore the growing season of rice in that country is longer.

The ratio of accumulated field evaporation to accumulated evaporation from free water surface decreases with the stage of growth of the rice plant after 40 per cent of the total submergence time has elapsed, while the ratio of transpiration to free water surface evaporation increases with the stage of growth up to 85 per cent of the submergence period.

The empirical formula derived is very easily used. The total net duty of water is found directly from free water surface evaporation during submergence season and average daily loss of seepage in the rice field. If there is no evaporation record, the value of the evaporation loss may be obtained by means of evaporation formulas.

The graph of distribution of water use is useful in design to determine the peak of the irrigation water demand or the amount required at any interval of time during the irrigation season.

Suggestions for future observations on rice irrigation water requirements

Although the empirical formula and distribution diagrams developed in this study are believed to be as reliable as was possible to obtain from the data available, better results could have been obtained if more data had been available. It is hoped to secure further data and to continue these studies at a later date.

In order to aid those seeking information on how such experiments should be carried out, the following list of desirable observations has been compiled :

(a) Climatological conditions
1. Evaporation from evaporation pan
2. Temperature
3. Wind velocity
4. Humidity

(b) Consumption of water in rice fields and the distribution through the entire irrigation season
1. Field evaporation
2. Transpiration
3. Seepage
4. Preparation of land or initial flooding
5. Depth of water in rice field

(c) Kind of rice and its growing condition
1. Kind of rice
2. Method of planting
3. Length of growing season
4. Dry grain produced

(d) Irrigation season
1. Date of first irrigation
2. Date of beginning of submergence
3. Date of end of submergence

(e) Geologic conditions
1. Mechanical analysis of surface soil
2. Mechanical analysis or permeability tests of subsoil
3. Ground water table elevation

APPENDIX

After completing the original paper, the authors received further information concerning rice irrigation from the Bureau of Plant Industry, Department of Agriculture. and Commerce, Philippine Islands, which they feel should be included in the report. Although sufficient data is not available for an investigation of computed value in comparison to those measured, it is believed it will be possible to secure information at a later date.

Experiments to determine the amount of water necessary to mature a normal rice crop were conducted in Alabang on Laguna de Bay, about 18 miles south of Manila, in the province of Rizal, Luzon Island, Philippine Islands. The soil is a black stiff clay, underlaid for the most part with adobe rock. In 1924 and 1926 the loss of water from the heavy clay rice soil of Alabang was determined in 65 paddies with a total area of 12,006 sq. ft. The depth of submergence was approximately 2·95 inches in 1924 and 2·44 inches in 1926. The observations were continued for 16 weeks (August to December) coinciding with the growing period of rice. The loss of water was determined by taking daily readings of the water level in the paddies. The irrigation water came from a well and discharged directly into the field through a pipe. Therefore the losses included only evaporation, transpiration and seepage. As the soil is underlaid by adobe rock, the percolation may be neglected.

In 1924 the total amount of water required for a second rice crop during the dry season was also determined in a rice field with an area of 14,158 sq. ft. The water was used during the irrigation period from January to May. In January a large amount of water was used in the preparation of the land. The soil was submerged slightly early in the month to encourage the growth of weeds and in the latter part of the month to prepare the seed bed.

The total amount of water used in each experiment is summarized as follows:

Year	Irrigation season	Total amount of water used, cubic meters per hectare	Total amount of water used, depth in inches
1924 . . .	**Aug. to Dec.** . .	**8,850**	**34·8**
1926 . . .	**Aug. to Dec.** . .	**9,993**	**39·2**
1924 . . .	**Jan. to May** . . .	**20,136**	**79·4**

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PLANT QUARANTINE NOTIFICATIONS

INDIA

Notification No. F. 43-32/20-A., dated January 16, 1941 of the Government of India in the Department of Education, Health and Lands

IN modification of this Department Notification No. F. 116/34-A., dated the 28th November 1935, it is notified for general information that the Government of Bombay have decided to levy a fee of Re. 1, in addition to incidental charges, to cover the cost of fumigation or disinfection, of each consignment of plants or fruits, intended for export to countries abroad, which is sent for inspection and certification to the Agricultural College, Poona.

Notification No. F. 43-15 (16)/40-A., dated February 4, 1941 of the Government of India in the Department of Education, Health and Lands

IN exercise of the powers conferred by sub-section (*1*) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to direct that the following further amendments shall be made in the Order published with the notification of the Government of India in the Department of Education, Health and Lands, No. F.-320/35-A., dated the 20th July 1936, namely :—

In the said Order—

(1) in sub-paragraph (1) of paragraph 5, after the words ' other than ', the words ' unmanufactured tobacco imported from Burma ,' shall be inserted : and

(2) in paragraph 8-B, after the words ' British India ', the words ' by sea ' shall be inserted.

Notification No. F. 15-2/41-A., dated February 12, 1941 of the Government of India in the Department of Education, Health and Lands

WITH reference to this Department notification No. F.-147/34-A., dated the 26th January 1935, it is notified for general information that the health certificate, required under Article I of the Decrees issued by the Governor General of Indo-China, dated the 8th March and 6th July 1933 relating to the importation of fruits into Indo-China, may be issued in the Province of Bombay by either the Plant Pathologist to the Government of Bombay or by the Professor of Entomology, Agricultural College, Poona.

Notification No. F. 15-9/41-A., dated March 6, 1941 of the Government of India in the Department of Education, Health and Lands

IN exercise of the powers conferred by sub-section (*1*) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to direct that the following further amendments shall be made in the notification of the Government of India in the Department of Education, Health and Lands, No. F. 320/35-A., dated the 20th July 1936, namely :—

In the First Schedule annexed to the said notification in columns 2 and 3—

(1) for the entry relating to ' Malay Peninsula ' the following entry shall be substituted, namely :—

Malay Peninsula . . .	The Department of Agriculture or/and Gardens, Straits Settlements, Federated Malay States and Unfederated Malay States.

(2) the entry relating to 'Straits Settlements' shall be omitted.

(3) against paragraph 7, after the entry relating to 'Burma', the following entry shall be inserted, namely.—

'Malay Peninsula . . . Head of the Pathological Division of the Rubber Research Institute.'

(4) against paragraph 8-A, for the entry relating to 'Burma' the following entry shall be substituted, namely :—

'Burma . . . . . Mr. L. P. Khanna, M.Sc., Lecturer in Biology, University College, Rangoon.'

GIPD—S3—730 IC of AR—26-6-41—750.

ERRATA

INDIAN JOURNAL OF AGRICULTURAL SCIENCE, VOL. 10, PART V

Page 754, line 22, Plate XXXIII, letterpress of fig. 2, Page 756, lines 7 and 17 and Table II, col. 1, line 1, Page 757, line 16 from bottom and Table III, col. 1, line 5,	*for* 'Kurakkan' *read* 'Kurkan'

Plate XXXIV, letterpress, *for* '(var. colour)' *read* '(var. Olour)'.

THE INDIAN JOURNAL OF AGRICULTURAL SCIENCE

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CONTENTS

VOL. XI, PART III

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